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ASD-TDR-63-181

HYDROGEN-OXYGEN PRIMARY EXTRATERRESTRIAL (HOPE) FUEL CELL PROGRAM

TECHNICAL DOCUMENTARY REPORT NO. ASD-TDR-63-181

May 1963

Flight Accessories Laboratories
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 8173, Task No. 817303

(Prepared under Contract No. AF 33(657)-8960 by
General Electric Company, Philadelphia, Pennsylvania)

NOTICES

35-865P, 200, 7-15-63

FOREWORD

This final report of the Phase Ia Hydrogen-Oxygen Primary Extraterrestrial (HOPE) Fuel Cell Program was prepared by the General Electric Company, Spacecraft Department (SD), Philadelphia, Pennsylvania, and the Direct Energy Conversion Operation, Lynn, Massachusetts, under Air Force Contract No. AF 33 (657)-8960. The systems, spacecraft and fuel cell controller design was accomplished by SD; the development of the fuel cell subsystem, consisting of the fuel cell modules, the water tank and associated components, was accomplished by the Direct Energy Conversion Operation (DECO) of the Ordnance Department.

The program was administered under the direction of the Static Energy Conversion Section (G. M. Kevern, Chief) of the Flight Vehicle Power Branch, Flight Accessories Laboratory; Captain G. E. Starkey was Project Officer.

The program, a continuation of Phase I, extended from June 1962 to October 1962, at which time it was terminated at the convenience of the government due primarily to the lack of a current Air Force operational requirement for fuel cells and the active development of fuel cells by NASA for the GEMINI and APOLLO programs.

Program personnel at SD included: A. Frank, Project Manager; R. J. Barchet, Systems; E. R. White, Consultant; W. G. Benton, Spacecraft Design; H. P. Marderness, Pneumatics; B. Zeldin, Thermal Analysis; J. Messingschlager, Ground Support; R. Luck and D. Tasca, Electronics; M. D. Read and W. S. Losew, Systems Test; and S. V. Koutsougianis was project secretary.

Key personnel at DECO responsible for the development of the HOPE fuel cell included: L. E. Chapman, Manager, Fuel Cell Projects and C. W. Snyder, Project Engineer.

ABSTRACT

The HOPE program was conceived in early 1960 by the Air Force Aeronautical Systems Division (ASD) as a program to advance the state-of-the-art of primary hydrogen-oxygen fuel cells by obtaining performance data of such energy conversion devices while operating under actual space conditions.

Phase I resulted in the development and environmental test of the double 35-cell, 25-watt/28-volt fuel cell subsystem, and the development of the fuel supply and structural subsystems. This included the water removal subsystem, fuel tankage, fuel controls, and fuel cell instrumentation.

Phase Ia was contracted to provide a Development Test Vehicle (DTV), Flight Vehicle (FV), and Flight Vehicle Backup (FVB) complete with fuel cells, fuel supply, fuel cell controllers and structural subsystems. Thorough systems testing of the Development Test Vehicle was planned for this phase.

After the Phase Ia program was approximately 50% complete, the program was terminated at the convenience of the government. The prime factors leading to this termination were:

1. The lack of a current operational requirement for fuel cells by USAF.
2. The accelerated development of fuel cells by NASA for the GEMINI and APOLLO programs.

Prior to termination, the fuel cell and pneumatics subsystems had undergone functional testing and a Fuel Cell Controller had been developed. The Development Test Vehicle, complete with all experimental subsystems, was being readied for systems testing.

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INTRODUCTION

The HOPE program was conceived in early 1960 by the Air Force Aeronautical Systems Division (ASD) as a program for developing and orbiting a primary hydrogen-oxygen fuel cell.

General Electric was awarded the contract for the Phase I HOPE program in April 1961, the Missile and Space Vehicle Department - subsequently renamed as the Spacecraft Department (SD) - being designed as prime contractor for the HOPE satellite system. Fuel cell development responsibility was assigned to the Direct Energy Conversion Operation (DECO) in Lynn, Massachusetts. The HOPE program was a multiphase effort, the prime objective of which was to advance the state-of-the-art of primary hydrogen-oxygen fuel cells by obtaining performance data of such energy conversion devices while operating under actual space conditions. The key technical objectives were to establish the degree of influence a zero-gravity environment exhibits on:

- The electrochemical reactions necessary to primary fuel cell operation;
- Hydrogen ion diffusion through polymeric membranes;
- The internal mass transport of water through the phenomena of capillary action; and
- The mass transport of water vapor through an ambient of diatomic oxygen gas at one atmosphere pressure.

The ultimate objective of the HOPE program was the design of a 500-watt fuel cell power system, including cryogenic fuel supply, for orbital applications.

The HOPE program was planned in phases to allow the orderly completion of the technical milestones necessary to the economic development of the entire fuel cell system. The multiphase program consisted of Phases I, Ia, II and III.

Phase I resulted in the development and environmental test of the fuel cell subsystem, and the development of the fuel supply and structural subsystems. This included the water removal subsystem, fuel tankage, fuel controls, and fuel cell instrumentation.

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Phase Ia was contracted to provide a Development Test Vehicle (DTV), Flight Vehicle (FV), and Flight Vehicle Backup (FVB) complete with fuel cells, fuel supply, fuel cell controllers and structural subsystems. Systems testing of the Development Test Vehicle was to include thorough environment testing by a planned sequence of the following systems tests:

- 7-Day Bench Test
- 7-Day Thermal/Vacuum Test
- Proof Pressure/Leakage Test
- Shock Test
- Acceleration Test
- Vibration Test
- Proof Pressure/Leakage Test
- 7-Day Bench Test

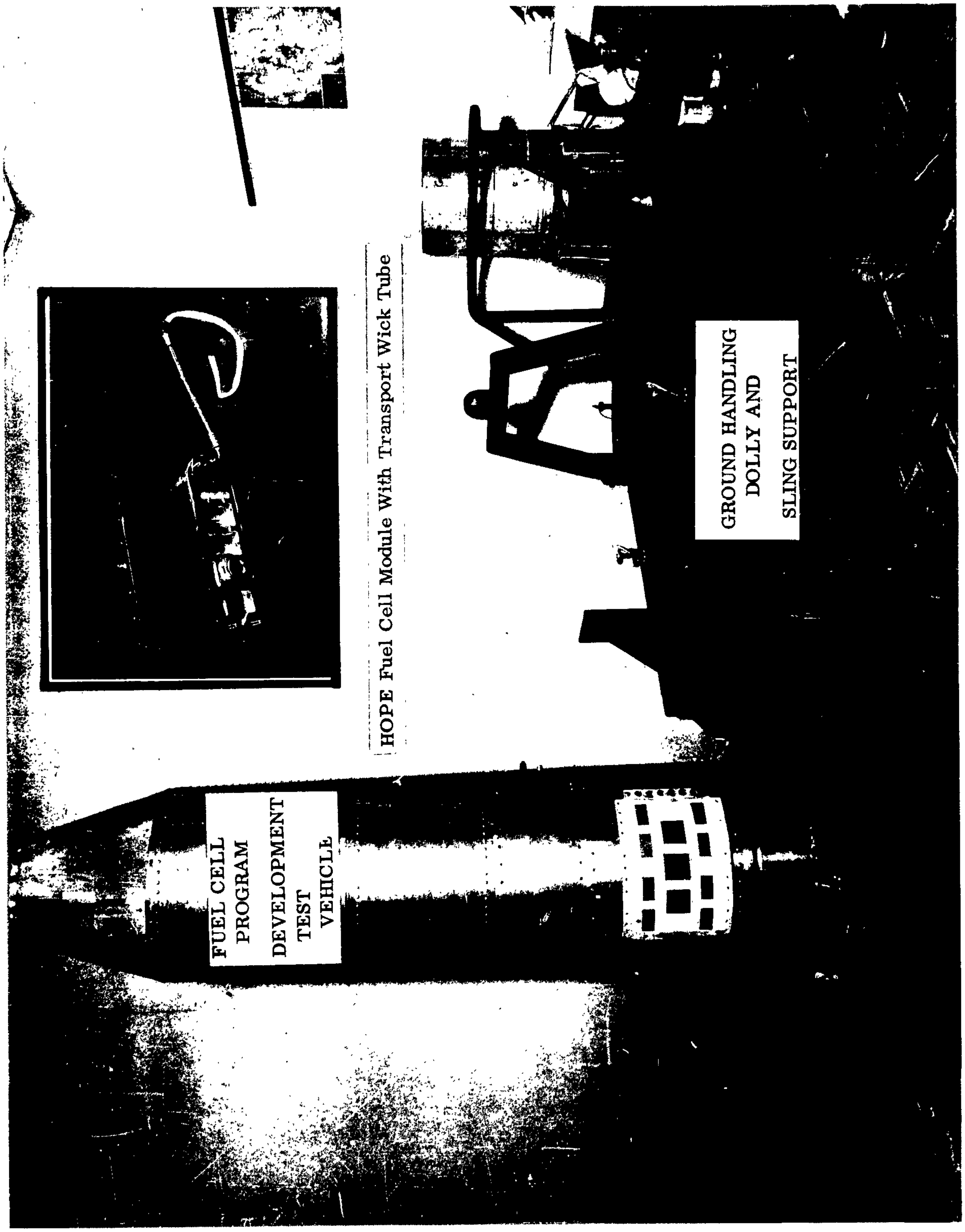
Phase II was to provide for the development of the support subsystems necessary to the successful conduct of the launch and orbit operation of the fuel cell subsystem and for the integration of these subsystems into the HOPE spacecraft. These subsystems include de-spin, data acquisition (telemetry), and ground support. In addition to the actual launch and orbital experiment, this phase also was to provide for the integration of the HOPE system into the fourth stage of the Improved Blue Scout Booster Vehicle.

Phase III was to provide for the design of a complete 500-watt fuel cell power system, including fuel supply and controls, and incorporating the findings and conclusions of the preceding phases.

After the Phase Ia program was approximately 50% complete, the program was terminated at the convenience of the government. The prime factors leading to this termination were:

1. The lack of a current operational requirement for fuel cells by USAF.
2. The accelerated development of fuel cells by NASA for the GEMINI and APOLLO programs.

This report describes the activities conducted on the HOPE Phase Ia program prior to its termination. (The description of the HOPE Phase I program is contained in Technical Documentary Report No. ASD-TDR-62-522, dated June 1962.)


HOPE Fuel Cell Module With Transport Wick Tube
FUEL CELL PROGRAM DEVELOPMENT TEST VEHICLE
GROUND HANDLING DOLLY AND SLING SUPPORT

SECTION 1.

FUEL CELL SUBSYSTEM

L. Chapman, DECO
C. Snyder, DECO

SECTION 1. FUEL CELL SUBSYSTEM

1.0 Introduction:

This section of the report describes engineering progress by the General Electric Company's Direct Energy Conversion Operation during Phase I-a on the testing of the fuel cell subsystem components and on the procurement and fabrication of qualification systems to be tested in conjunction with the spacecraft subsystems. The effort was primarily concentrated on module testing, stack testing and component procurement and fabrication. Figure 1-1 shows the final configuration of the fuel cell module.

1.1 Module Testing:

Three fuel cell modules were assembled and tested during Phase I-a. Module T-2 was reassembled following vibration testing and tested at various ambient temperature conditions and load levels to determine its performance stability.

Module T-1 was retrofitted with new cells and tested for pneumatic system and fuel cell controller compatibility. Later it was mounted on a space radiator to check out operating characteristics in M & SD's bench test configuration at the Spacecraft Department.

Qualification module Q-1 was fabricated and tested according to the 48-hour acceptance test procedure. Proof pressure and leakage tests were then performed and passed. A discussion of these tests is given in Section 1.3.2.

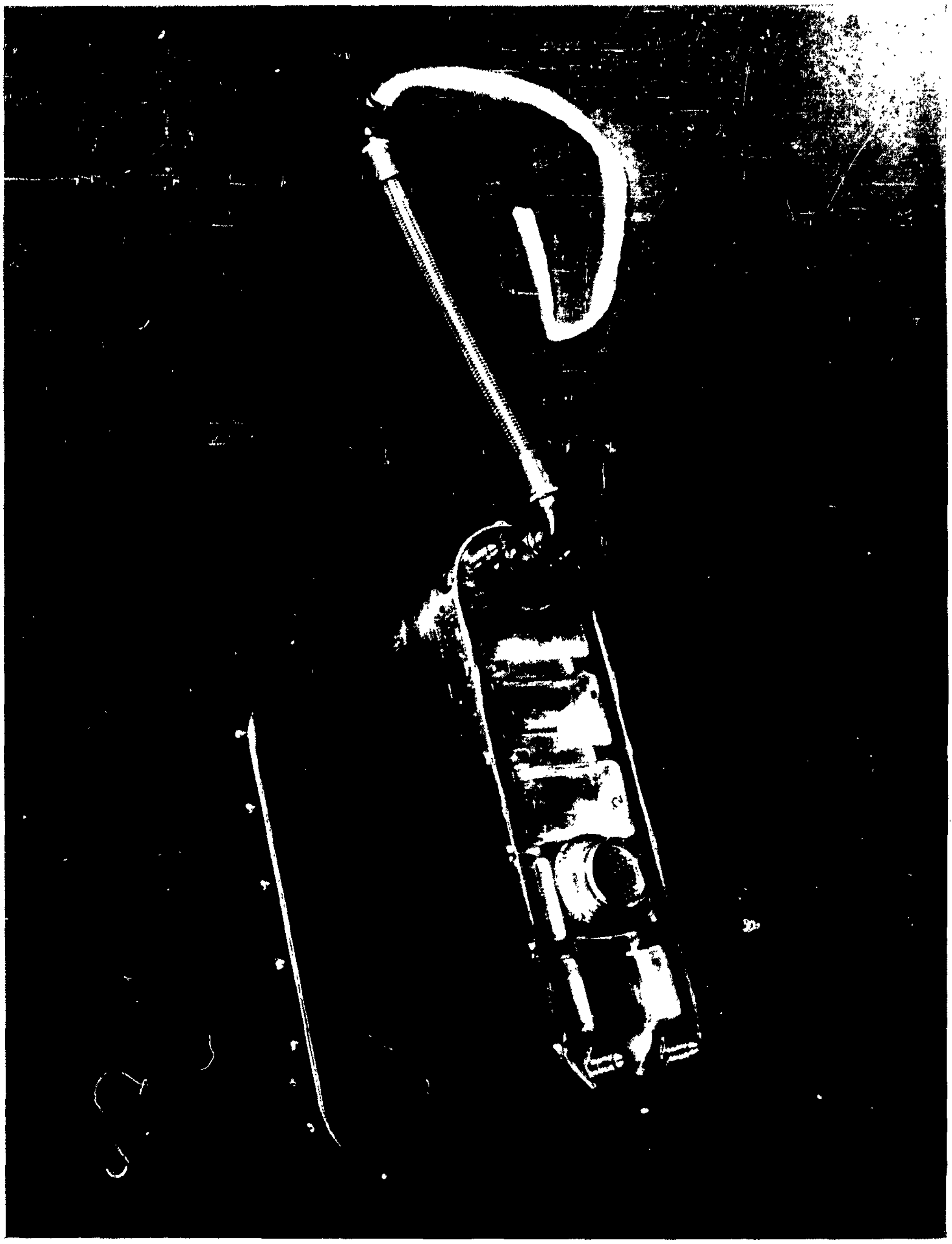


Figure 1-1. HOPE Fuel Cell Module with Transport Wick Tube

1.1.1 Increased Power Tests:

Module T-2 was operated for short periods of time at various load points up to 50 watts. Figure 1-2 shows module voltage as a function of power output. During the test, the module was clamped to a heat sink which was maintained at 100°F. The ambient temperature was held at 110°F. Figure 1-2 also shows the cell temperature as measured by thermistors located on the O_2 side of the cell between the membrane and the collector. The results of this test showed that the HOPE module is capable of 50 watts output at 28 volts.

1.1.2 Cycling Heat Sink Temperature Tests:

Module T-2 was then subjected to a test wherein the temperature of the heat sink was cycled between 70°F and 110°F at a frequency of 0.66 cycles/hour (90 minutes from 70°F to 110°F and back to 70°F). Figure 1-3 shows heat sink temperature and module internal temperature as a function of time. It can be noted that the module temperature varies only 22°F for a heat sink temperature fluctuation of 40°F. Also, the peak temperature of the module lagged the heat sink temperature peaks by about 9 minutes. Figure 1-3 also shows module power and voltage vs. time.

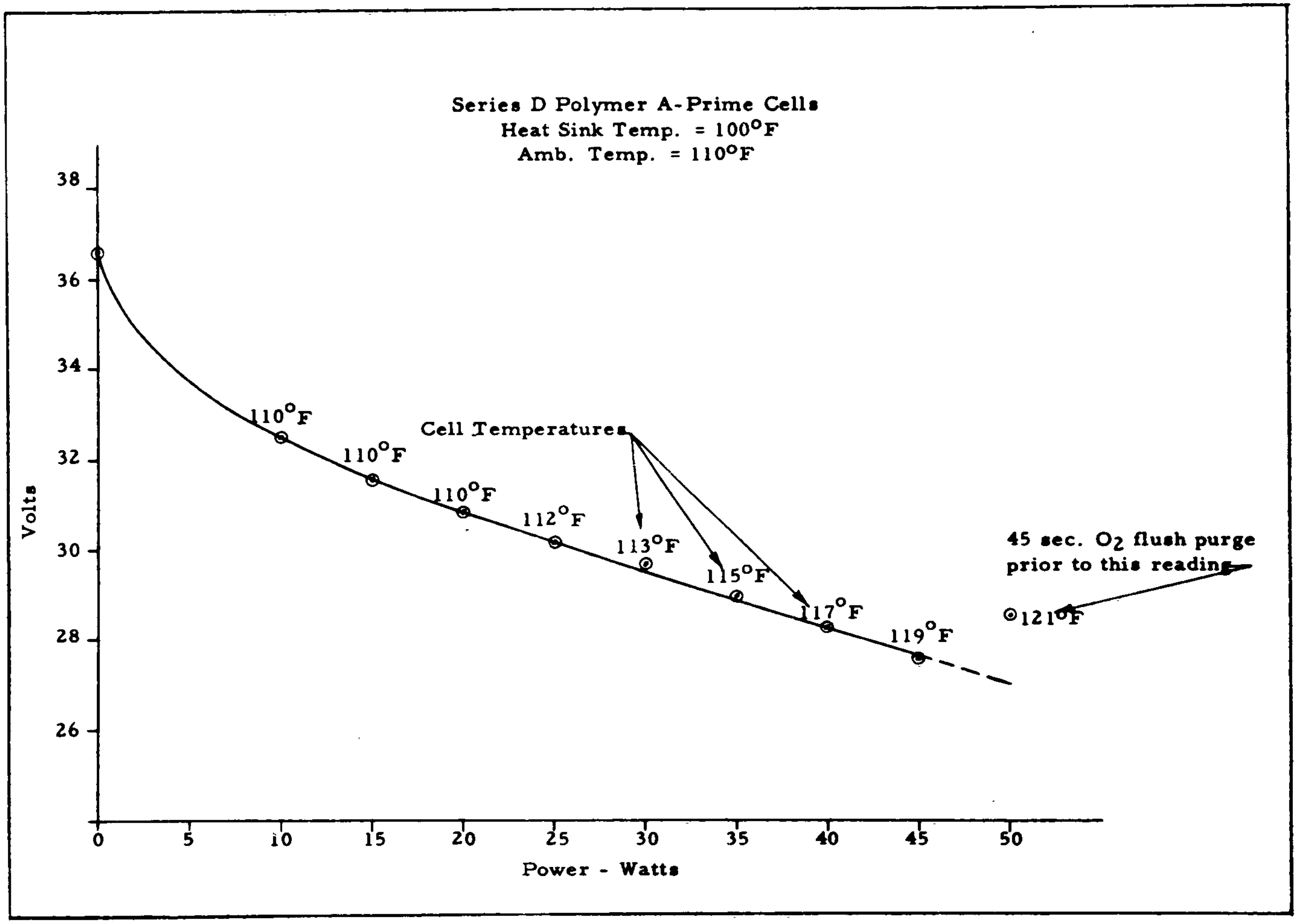


Figure 1-2. HOPE Fuel Cell Module T-2, Voltage vs. Power

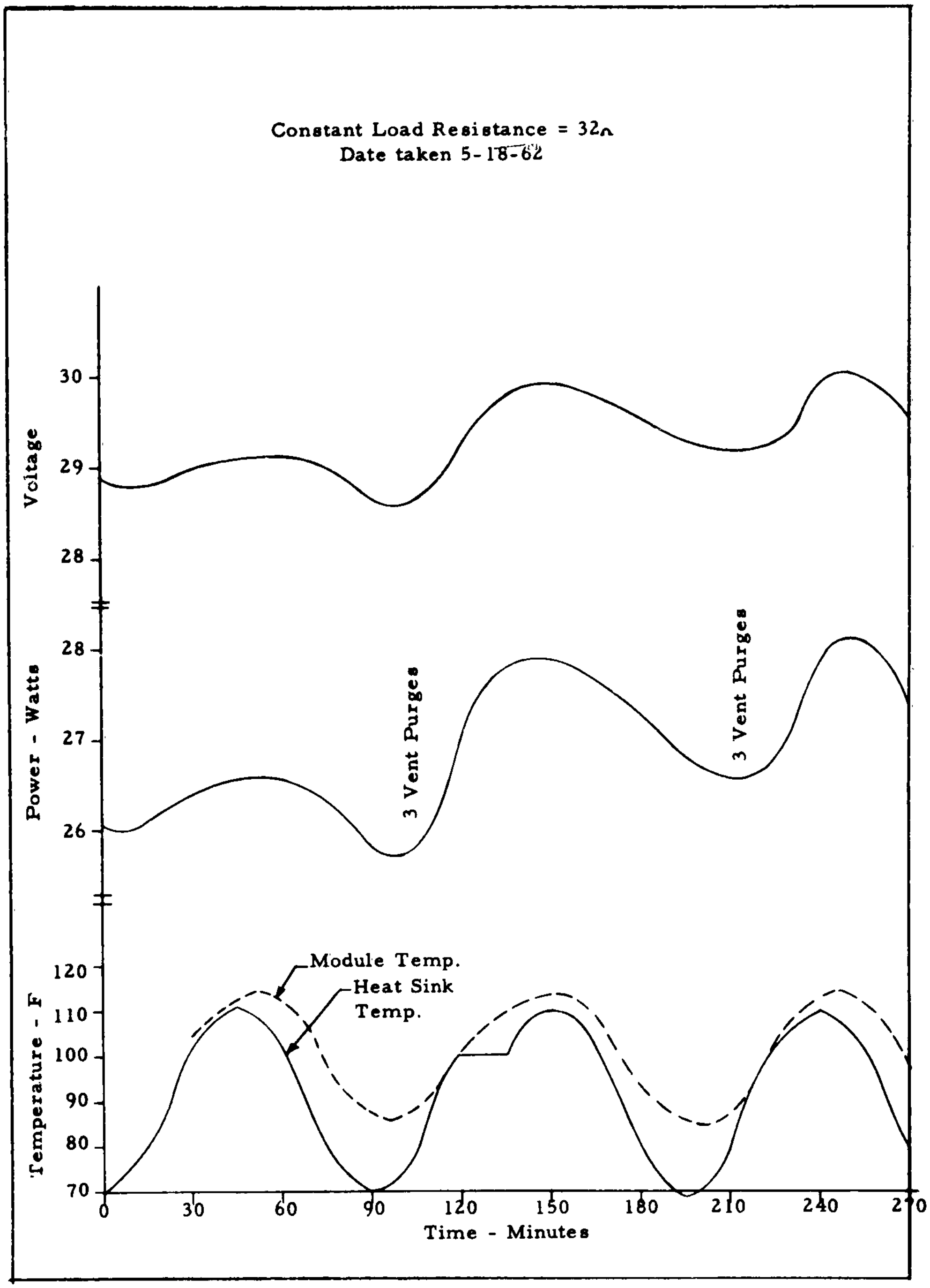


Figure 1-3. HOPE Fuel Cell Module T-2, Thermal Transients

1.1.3 Performance Stability Tests:

A series of tests were then run on Module T-2 to determine the effect that various conditions of heat sink temperature, ambient temperature, and hydrogen - oxygen differential pressure have on the output power and on the required purge frequency.

The conclusions drawn from the results of these tests are listed below:

- A simultaneous purge of H_2 and O_2 gases is most effective in maintaining performance. A vacuum purge of the O_2 side to 13 psia does not satisfactorily maintain performance.

- The module operates satisfactorily during the "cold case" thermal conditions. Power output was 25.0 watts at 28.9 volts.

- The fuel cell operates satisfactorily during the "hot case" thermal conditions. Power output was 26.5 watts at 29.7 volts.

- Stable performance is provided by the fuel cell at a heat sink temperature of 100°F.

- Performance drops slightly when the O_2 pressure is raised above the H_2 pressure.

- Performance increases slightly with increased temperature.

1.1.4 Pneumatic System and Fuel Cell Control Subsystem Tests:

Based on the results of module, stack and performance stability testing, an attempt was made to define a purge technique that would satisfy the requirements of the fuel cell module. The resulting procedure is outlined in the "Proposed Purge Method for HOPE Fuel Cell" in Appendix I-A. This discussion specifies the pressure limits and time limits that were to be maintained by the pneumatic system. However, subsequent to pneumatic system compatibility testing resulted in modifications to these limits.

The pneumatic system was designed and fabricated by the Spacecraft Department. A more detailed discussion of the system can be found in Section 3 of this report.

The fuel cell control subsystem (fuel cell controller) was designed to perform the following functions:

- Provide fuel cell purge sensing
- Provide fuel cell overtemperature control
- Provide fuel supply and purge valve control

The design and procurement of the fuel cell controller was the responsibility of the Spacecraft Department. A complete discussion of the requirements and a description of the equipment can be found in Section 2 of this report.

In order to establish the purging and control limits to insure compatibility between the pneumatic system, the controller, and the fuel cell module, tests were run at DECO using breadboard pneumatics and controller to operate with fuel cell Module T-1.

The tests were performed in the following sequence:

- Pneumatic system checkout using simulated fuel cell volumes and manual operation of the pneumatic system.
- Fuel cell operation with manual operation of the pneumatic system.
- Fuel cell operation with controller activated pneumatic system.

For the pneumatic system checkout, the equipment was assembled as in Figure 1-4, which shows a 25 cubic inch cylinder in place of the fuel cell hydrogen side and a short length of tubing in place of the fuel cell oxygen side. The breadboard controller provided a convenient method of varying the H_2 purge time because of its built-in time adjustment. The test of the H_2 purge system included the following steps:

- Evacuate the H_2 vacuum tank to a pressure less than five inches Hg.

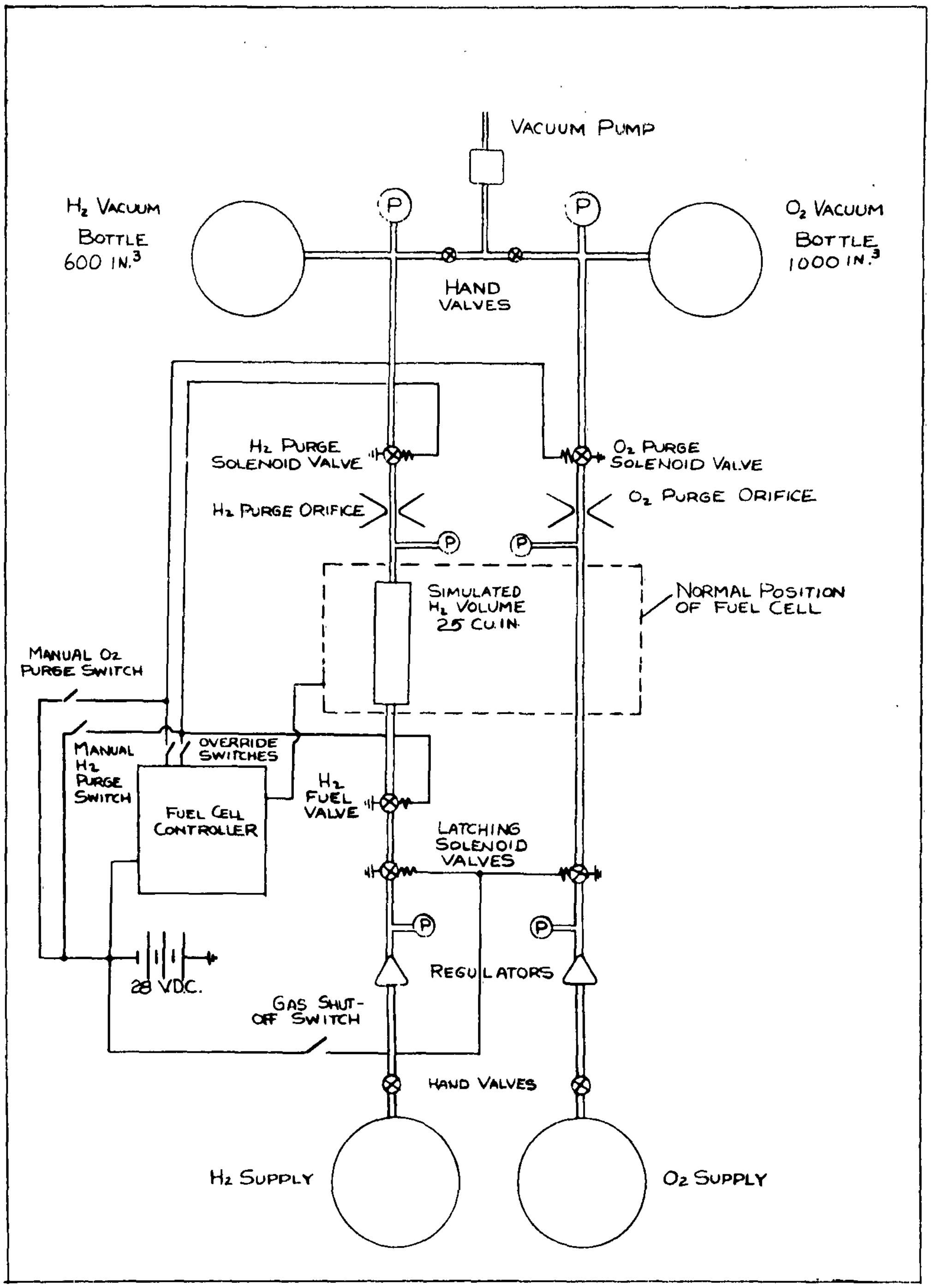


Figure 1-4. Pneumatic System and Fuel Cell Test Setup Schematic

- Perform H_2 purge sequences with various time lengths noting the pressure to which the H_2 pressure drops within the H_2 side simulated volume.

- Adjust the orifice size and purge time to meet the specification requirements.

The results of the checkout tests showed that the pneumatic system H_2 orifice of .014 inch diameter provided a pressure drop of four inches of mercury for a purge time of 1.2 seconds.

The test on the O_2 purge system included the following steps:

- Evacuate the O_2 vacuum tank to a pressure less than five inches Hg.

- Perform O_2 purge sequences with various time lengths noting the O_2 purge flow and the minimum O_2 pressure reached.

- Adjust the orifice size to meet the specification requirement.

The O_2 system checkout showed that the O_2 pressure within the module would drop 12 to 13 inches H_2O with a purge flow of 1750 cc/min. using a .020 inch diameter orifice. A 45 second purge time was used. Next the fuel cell was installed into the system and the same purge sequences actuated as described above.

It was found that the H_2 orifice had to be enlarged to .0305 inches diameter to obtain a pressure drop of 4 inches Hg in 2.2 seconds. The oxygen side purge characteristics remained unchanged. It became apparent that each test setup would have to be evaluated independently in order to compensate for line volumes and losses.

The fuel cell module was then operated at 27 watts for several hours with the pneumatic purge system being actuated manually (without sensing by the fuel cell controller).

After several hours of satisfactory fuel cell operation, the controller was connected at the cell voltage taps so that it would sense purge requirements. The controller was set to initiate one H_2 purge when the voltage across any group of 3 cells dropped below 2.1 volts, and one 45 second O_2 purge when the total module voltage dropped to 27.5 volts. Each 2.2 second vent purge caused a momentary pressure drop of 4 inches mercury on the H_2 side of the cells. The O_2 flowing during the 45 second purge was measured at 1700-1800 cc/min. with a pressure drop on the O_2 side of 12 to 13 inches H_2O. The module was then operated continuously for approximately 44 hours. During the first 15 hours the purge frequency increased from an initial value of one every 2 hours to one every 5 minutes.

This purge requirement was caused by a number of nosediving cells, which actuated H_2 vent purges only. At no time did the total module voltage drop below 29.0 volts, and thus no O_2 flush purges occurred. Such an H_2 purge frequency was considered much too high. A 45 second O_2 purge, which was manually actuated, corrected the situation and the H_2 purge requirement decreased to one every 4 or 5 hours during the next 13 hours of operation.

For the next 10 hours a purge sequence of 3 H_2 vent purges and one 15 second O_2 flush purge was used resulting in an average purge frequency of once every 5 hours.

During the last 8 hours of the test, the O_2 purge was not used and the fuel cell operation proved satisfactory.

After studying the results of these tests, it was concluded that:

- Both an H_2 and an O_2 purge should be initiated whenever the voltage on a 3 cell group began to drop off.

- The total module voltage could not be used as a signal for activating an O_2 purge.

During the 44-hour test the fuel cell module operated between 29.0 and 29.8 volts at 0.88 to 0.90 amps. (25.5 to 26.8 watts). This was in addition to the power required by the fuel cell controller. The 3-cell group voltages averaged between 2.50 and 2.55 volts.

Both "hot case" and "cold case" conditions were run with no appreciable change in performance characteristics. It was, therefore, concluded that the pneumatics system and fuel cell controller were completely compatible with fuel cell module.

1.1.5 Simulated Bench Test

The 7-day bench test, which was to be performed at the Spacecraft Department on the first qualification system shipped, was to use air-cooled space radiators mounted in the development test vehicle. Fans or blowers would be used for cooling of the exposed radiating surface of each radiator while the module casing would be essentially insulated by the vehicle insulation.

Because there was some question whether or not satisfactory temperature control could be obtained with this type of setup, it was decided to simulate the setup at DECO using the T-1 test module.

The module was assembled with the radiator and pressure plate and the assembly was then wrapped with two inches of glasswool insulation so that only the curved radiating surface was exposed. (See Figure 1-5.) A small blower was directed against this surface. The blower flow could be regulated by restricting the inlet port.

The module was operated at 25 watts minimum for a continuous period of 22 hours. The first 5 hours were required to obtain the following stabilized thermal conditions:

Figure 1-5. Simulated Bench Test Setup

Module cell temperature . . . . $98^{\circ}F$

Heat sink interface temperature . . . . $100^{\circ}F$

Exposed radiator surface temperature. . . . . $92^{\circ}F$

The purge method used was one H_2 vent purge (2.2 secs. with a pressure drop of 4 inches mercury) and one 15 second O_2 flush purge. The fuel cell controller was used to sense low voltages in the cells and to initiate the H_2 purges. The O_2 purges were manually actuated. For the first 4 hours the unit was run with the radiator facing horizontally, the cell wicks in the module draining down. The unit was then re-positioned so that the radiator faced vertically up so that the cell wicks were draining water horizontally. The performance decreased slightly when the unit was reoriented but stabilized at 26.5 watts. The conclusion drawn from this test was that the 7-day bench test can be run using blower cooling of the space radiator. The position of the vehicle should be with the radiators facing vertically up and down to provide for horizontal removal of product water along the cell wicks. Such a position of the development test vehicle would also maintain the transport wick tubes essentially horizontal in both modules.

1.1.6 Purge Limits Summarized

After completion of the acceptance test on Module Q-1 (see Section 1.3.2), the purging format and limits were finalized for use in the 7-day bench and thermal vacuum tests to be run at the Spacecraft Department. These can be summarized as follows:

Purging Format:	One H_2 vent purge plus one 15 second O_2 flush purge.
Purge Initiation:	When a group of 2 or 3 cells in series reaches an undervoltage condition of 1.5 or 2.25 volts, respectively.
Time Delay:	A second purge will be initiated after a time delay of 15 seconds if the undervoltage condition is not corrected by the first purge.
H_2 Vent Purge:	To provide a pressure reduction of 2 psi in the H_2 side of the cells and to accomplish this in approximately 2 seconds.
O_2 Flush Purge:	To provide a flow of O_2 through the module case at the rate of 1750 cubic centimeters per minute with a maximum pressure reduction in the O_2 side of 0.5 psi.
Superimposed Purge:	To provide, in addition to the above, a purge every 2 hours.
Limit on Purges:	The number of purges to be limited to 4 every 2 hours.

1.2 Stack Testing

During Phase I-a, storage tests were run on four and five cell stacks of Polymer A-Prime Series D Cells in laboratory test boxes. Also completed was a 2000 hour life test on a 6-cell stack of Series D Cells.

1.2.1 Storage Testing

The types of storage tests run were active and inactive. Active storage is when H_2 and O_2 remains in the cells at operating pressure. Inactive storage is when the H_2 and O_2 lines are disconnected and atmospheric air is allowed to contact the cells on both sides.

The active storage test was run on a 5-cell stack after it was operated for four hours at 0.94 amps. It was stored under H_2 and O_2 at open circuit for 30 days and then purged and operated for a continuous 7-day period at 0.9 amps. The average performance during the 4 hour test was 0.796 volts at 0.94 amps. During the storage period the open circuit voltage dropped from 1.06 volts per cell to 0.95 volts per cell. The average performance during the 7-day continuous load test was constant at 0.81 volts per cell at 0.9 amps. This is equivalent to 25.5 watts in a 35 cell module.

The inactive storage test was run on a 4-cell stack after a 6-hour operating test at 0.9 amps. It was then deactivated by removing the H_2 and O_2 inlet lines and shorting all cells to each other to reduce the voltages to zero. After 3 days open to atmosphere, to insure that all H_2 had been consumed, the H_2 and O_2 lines were capped.

After a 38-day storage period the short circuits were removed in preparation for running a 7-day continuous test. In an attempt to activate the cells by purging, two cells appeared to be leaking. Upon subsequent leak and pedigree testing, only one cell was found to leak.

The leak turned out to be a small hole in the membrane apparently caused by a short circuit between the two screen electrodes on either side of the membrane.

The other cell apparently had leaked in the tubing in the test box. The remaining 2 cells were operated at 1.0 amps for a continuous 7-day period. The average performance (0.86 volts at 1.0 amp) was the same as it had been prior to storage.

The results of the inactive storage test were encouraging but inconclusive. Since an adequate method of inactive storage on N_2 and O_2 had been proven during Phase 1 and funding for development testing was limited, it was decided not to continue this type of testing.

1.2.2 Life Testing

The Phase 1 final report described the testing that was done on Polymer A Prime Series "D" Cells near the end of HOPE Phase 1. By that time 468 hours had accumulated on 6 cells and 486 on the seventh of the 7-cell life test stack.

As work commenced on Phase 1-a, the life test continued. The stack was finally disassembled for inspection and analysis after close to 2000 hours of operation at 0.9 amps. The following chart summarizes the life test results.

Operating Time (Hours)					Performance Level (Volts)		
Cell #	Test 1	Test 2	Life Test	Total	Start Test 1	Start Test 2	End Life Test
D46		154	1810	1964		0.81*	0.75**
D32A		154	1810	1964		0.86*	0.74**
D18	172		1810	1982	0.83*		0.72**
D34		154	1810	1964		0.85*	0.74**
D27		154	1810	1964		0.85*	0.79**
D37		154	1810	1964		0.85*	0.76**
D32		154	365	519		0.81*	0.84**

* at 0.9 amps

** at 0.88 amps

The performance of the cells decreased approximately 12 percent. Examination of the cells at the end of the life test showed that none leaked. However, a lab analysis showed them to contain heavy contamination of iron and copper ions. The iron had come from the carpenter 20 collectors (ribs contacting the cells) and the copper from the copper collector core during storage in a wet polyethylene bag subsequent to the test but prior to the analysis.

The performance degradation is, therefore, attributed to the presence of the iron.

1.3 Qualification System Fabrication

Authorization had been received from ASD to manufacture two complete qualification systems plus one spare fuel cell module for systems testing at the Spacecraft Department. Flight system release was not received on any hardware except the bipolar collectors which were also to be completed because of their long lead time.

Each qualification system includes two fuel cell modules, one double compartment water storage reservoir and two transport wick connecting tubes with wick disconnects.

Early in Phase I-a certain design modifications had to be made in the fuel cell and water tank assemblies to simplify manufacturing procedures and to improve the quality of the hardware.

As soon as the design changes were incorporated into the drawings, effort was concentrated on improving assembly and test procedures.

1.3.1 Design Modifications

The design changes made during Phase I-a are listed below:

- Incorporation of flexible transport wick tube
- Incorporation of wick disconnect device
- Enlarging of water storage reservoir

- Modifying H_2 inlet and purge tube configuration on cell assembly
- Incorporation of spacer in cell stack
- Change from terminal connection to riveted connection on cell voltage tap
- Removal of thermistor circuits from within the module case and change type of thermistor

Appendix I-K contains copies of all the drawings which incorporate the above changes.

1.3.2 Fuel Cell Module Fabrication and Test

1.3.2.1 Bipolar Collectors - The manufacturing procedure for the bipolar collectors, developed during Phase 1, was modified somewhat to improve quality and reduce costs. The dip tinning process was replaced by electroplating, and the hot press soldering operation was improved by providing for a simplified rib alignment method. A description of the manufacturing procedure for the bipolar collector is included in Appendix I-B.

1.3.2.2 Cell Assembly - The cell assembly contains four major components: the bipolar collector, the frame, the cell (membrane), and the product water cell wicking.

During the manufacture of cell assemblies for modules T-2 and T-1 (retrofit), considerable trouble was encountered with plugging of H_2 inlet and purge passages in the frames. To correct this condition, the gas passage was changed from a slot in the cycolac frame to a bonded-in stainless steel tube. In order to accommodate this modification it was also necessary to change the position of the manifolds and increase the length of the silicone rubber connecting tubes.

With the introduction of the Polymer A - Prime Series D cell, the bonding cement had to be changes from Bostick #588-83 to Scotchcast Resin #XR5046. In addition to this it was necessary to modify the bonding fixtures so that the outside edges of the oxygen screen electrode could be bonded to the membrane for added strength of the cell. A detailed description of the assembly procedure for the cell assembly is includedin Appendix I-C.

1.3.2.3 Thermistors - The latest module design included nine thermistors, each one mounted in the center oxygen channel of every fourth cell in the stack. (See Drawing 1076520-226 Appendix I-K.)

Since the first thermistor design (Phase I type) was found to be unsatisfactory because of short circuiting to the bipolar collectors, a new thermistor was procured from Gulton Industries, Matuchen, N.J. The latter design consisted of a completely encapsulated bead with Teflon insulated lead wires. The thermistor procurement specification is contained in Appendix I-D.

All thermistors for modules Q-1 and Q-2 were calibrated in the range from 80°F to 185°F. Figure 1-6 shows a typical calibration curve. An insulation resistance test was also made at 50 volts prior to installation in the modules.

During the 48 hour acceptance test on module Q-1, which is discussed in Section 1.3.2.6, all thermistors operated stably and accurately.

1.3.2.4 Pedigree Testing and Cell Assembly - Near the end of Phase I module T-1 was assembled with Polymer A Series D type cells, tested at rated load for 168 hours, vibration tested at specification conditions and then performance tested for more than 130 hours at rated load. In the course of running these tests, it was apparent that several cells required purging more frequently than the others. Cell #14 in particular required considerable purging during the 130-hour Performance Stability Test (Section 1.1.3). These unstable cells were suspected of having restricted hydrogen inlet or purge passages. Therefore, the module was disassembled for evaluation and examination of gas passages. A flow test on each cell showed that the unstable cells had partially blocked inlet or purge lines. The inlet line to cell #14 was completely blocked to water flow for a pressure of 1 psig.

The subsequent clearing of the gas passages on all cells took several weeks during which time all cells were subjected to handling and various periods of cement curing and storage.

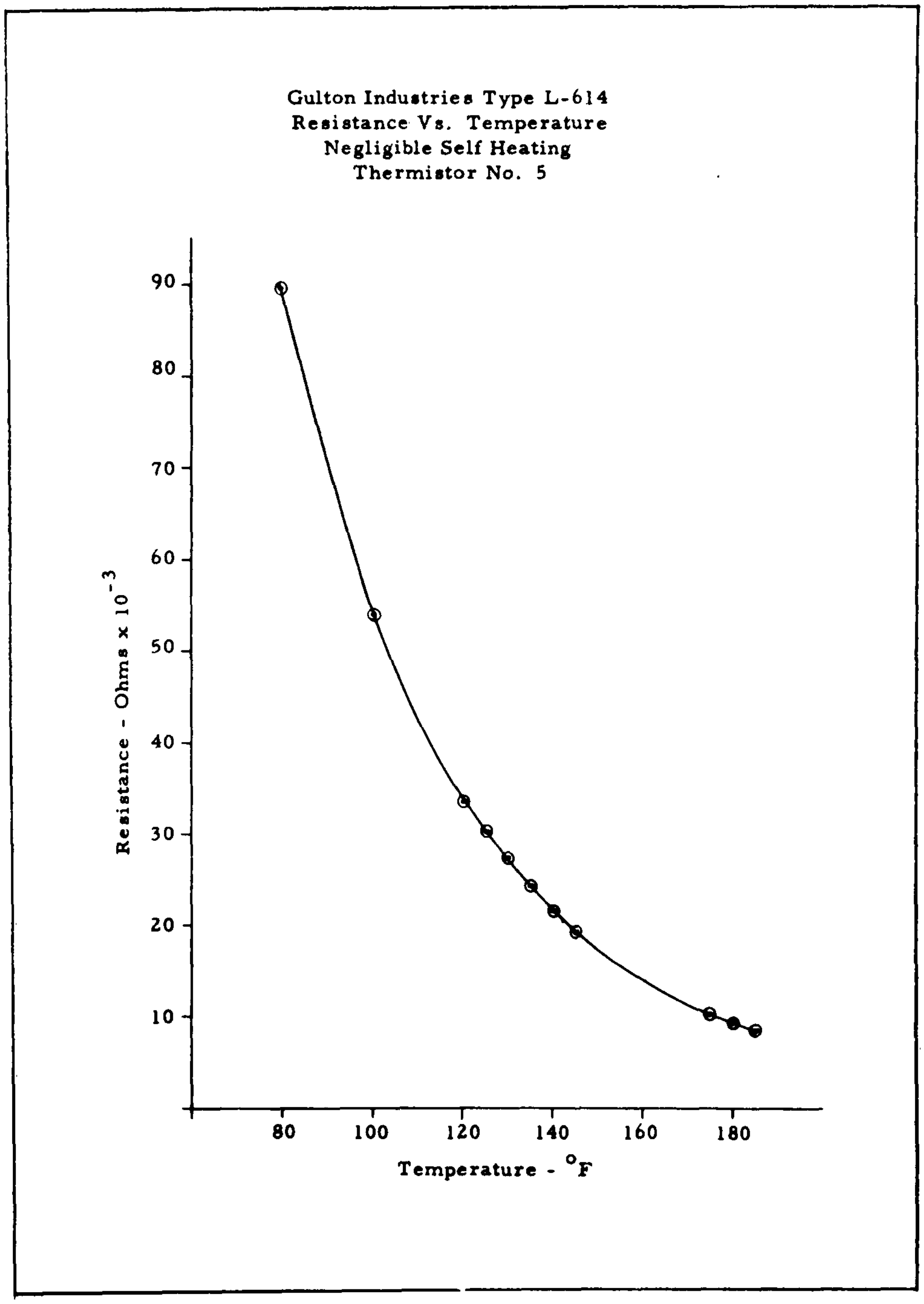


Figure 1-6. Typical Thermistor Calibration Qualification Unit Design

When the module was reassembled and tested, many of the cells were found to contain small membrane leaks. Further study of this condition led to the conclusion that the leakage had been caused by excessive drying of the membrane polymer during the period when repairs were being made to the hydrogen passages.

To prevent recurrence of drying conditions all cells were carefully maintained in a moist state from the time they were received from the Pilot Plant until the finished cell stack was enclosed in the module casing. Furthermore, all cells were individually pedigree tested and then stack tested in 8 to 10 cell stacks prior to installation into the modules. The pedigree and stack test procedure is given in Appendix I-E. All cells in module T-1 (retrofitted) were both pedigree and stack tested. During the screening of cells for module Q-1 it was decided that pedigree testing was not necessary since only a few cells out of 40 failed pedigree. The stack testing, which more closely simulated actual unit conditions, was performed on all cells for modules Q-1, Q-2 and Q-3.

1.3.2.5 Assembly of the Modules - An important change in the assembly procedure was made during the buildup of module Q-1. The overall height of each cell assembly had to be maintained within a tolerance of .015 inch to insure uniform contact pressure of the cell heat sink edges when the module is clamped against the radiator.

Prior to building module Q-1, the cell heights were equalized by filing the top edges of the cycolac frames collectively after the 35-cell stack was assembled. This method was unsatisfactory because the stack had to be disassembled after the filing operation to remove the filings and the filing operation was suspected of creating frame leaks. To improve the method, a special fixture was provided which allowed filing each collector-frame assembly individually before bonding it to the membrane. All the cell assemblies for modules Q-1, Q-2 and Q-3 were processed in this manner and as a result, a minimum number of collector to frame leaks occurred. Appendix I-F gives the detailed module assembly procedure and record sheets.

Modules Q-1 and Q-2 were completely assembled prior to termination of the program. An assembled module is shown in Figure 1-1.

1.3.2.6 Module Acceptance Test - The acceptance test for the qualification modules consisted of operating at a minimum of 25 watts load for a continuous 48-hour period. Appendix I-H contains the test instructions for the acceptance test.

The purge method used primarily was a single H_2 vent purge plus a 15 second O_2 flush purge as described in Section 1.1.6.

Referring to Figure 1-7, which shows module voltage and power vs. time, it can be seen that during the first 22 hours of the test the module required purging about once every hour. However, all purges were initiated manually during this period because the module power approached the 25 watt minimum. On the 22nd hour an O_2 flush purge was maintained for 90 seconds and from that time on the module voltage and power characteristics became much more stable. It was concluded that the module had not been thoroughly enough purged at the start of the test. From the 22nd hour until the 42nd hour the purge every 2 hours satisfactorily maintained the performance level. Thus, no purges were actuated by low individual cell voltages. On the 42nd hour the unit was shut down by a malfunctioning emergency shutoff mechanism. The shutdown period was 3.5 hours.

During the acceptance test, the 9 thermistors were monitored by measuring and recording their resistances by means of a bridge circuit. For comparison, the heat sink temperature was measured by thermocouples. Figure 1-7 shows the heat sink temperature, the module temperature and thermistor resistance as measured during the 48-hour test.

The thermistor resistance was measured to an accuracy of 0.5 per cent which represents approximately one degree fahrenheit. It can be seen from Figure 1-8 that the thermistor provided satisfactory indication of temperature changes, well within the accuracy required for this application. The temperature differential between module and heat sink was consistently 5 to 6 degrees.

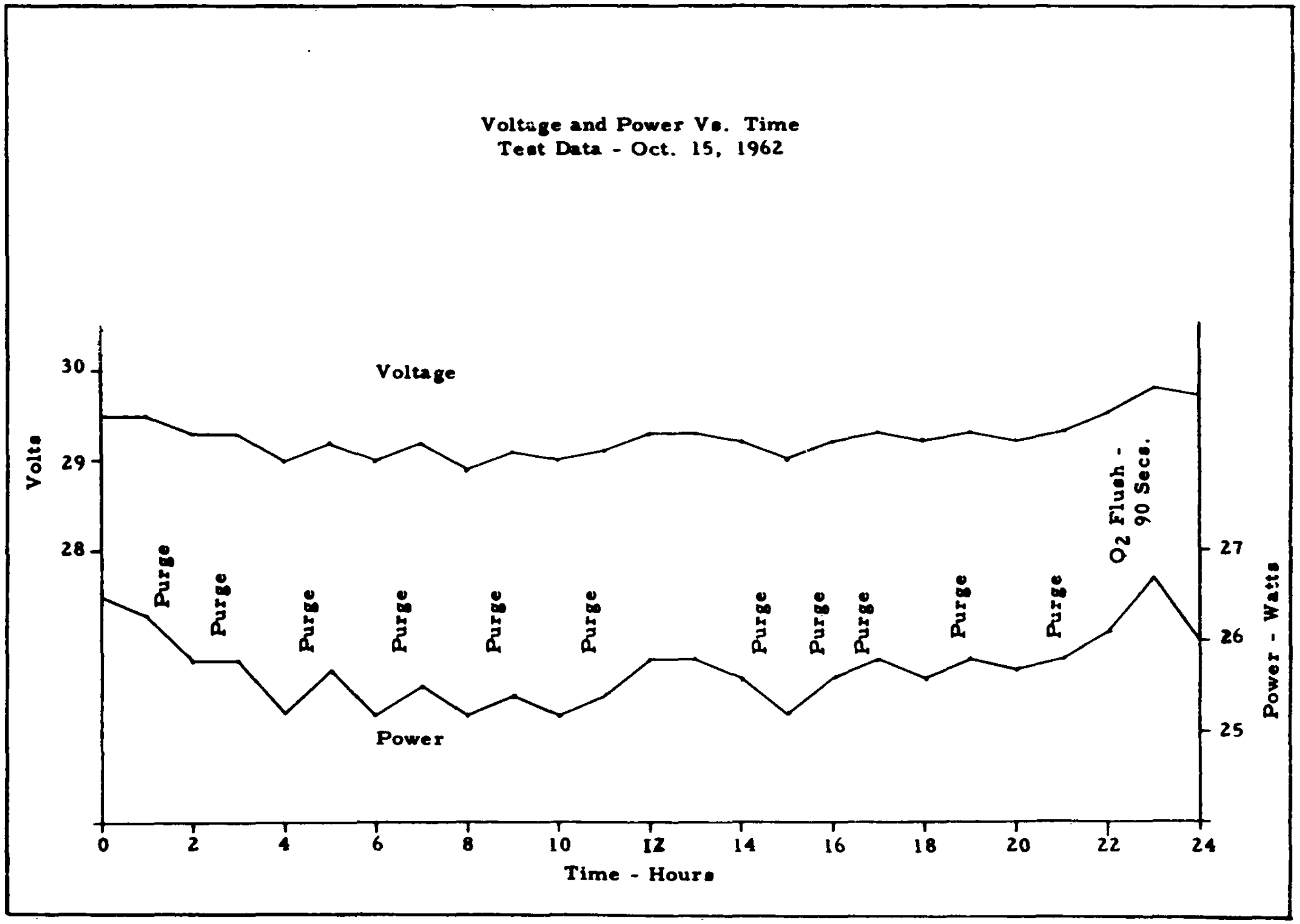


Figure 1-7. HOPE Fuel Cell Acceptance Test - Module Q-1 (Sheet 1 of 2)

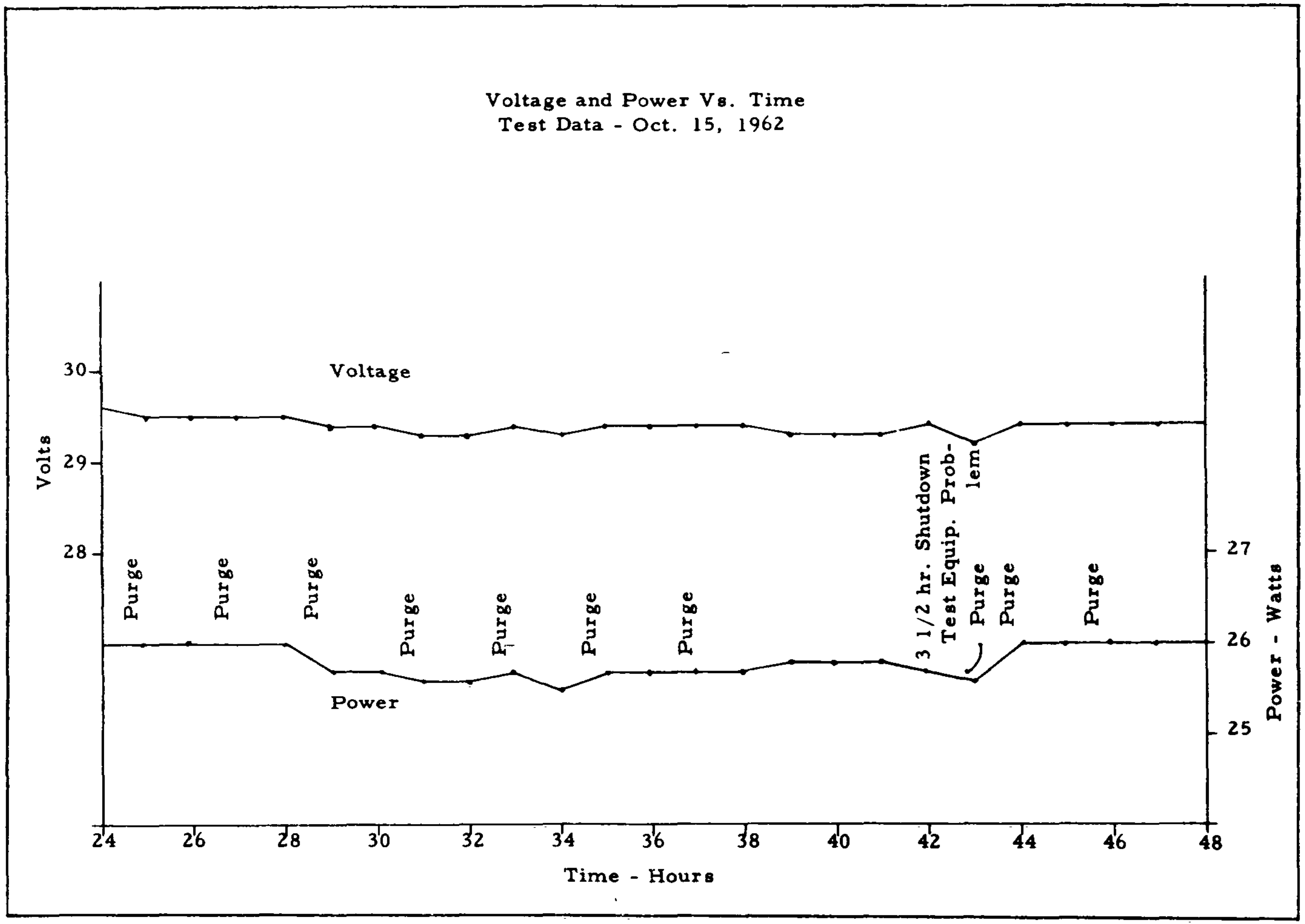


Figure 1-7. HOPE Fuel Cell Acceptance Test - Module Q-1 (Sheet 2 of 2)

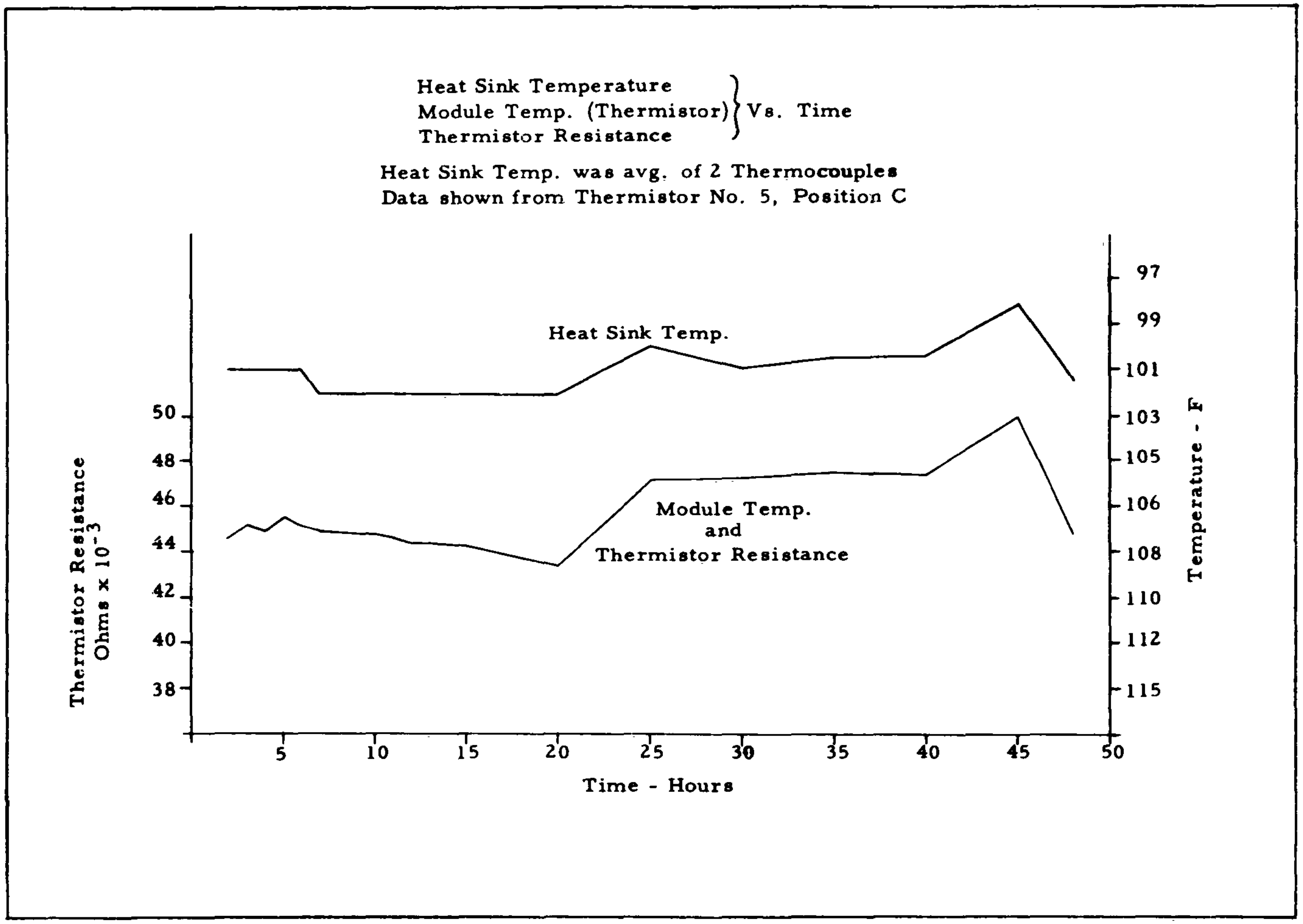


Figure 1-8. Acceptance Test Results - Module Q-1

After completing the 48-hour performance test, the module was disconnected from the water storage reservoir used for testing and connected to the flexible tube, wick d sconnect and qualification water storage tank. The system was then proof pressure tested at 45 psia N_2. The system was submerged in water to detect leaks. No leaks existed.

Module Q-1 and its respective transport wick tube, disconnect, and water tank satisfactorily passed the acceptance test.

1.3.3 Water Reservoir

The water storage reservoir absorbs the fuel cell product water which is transported to it by means of the transport wick. The tank consists of two stainless steel compartments, one for each 25-watt module, separated by an epoxy glass laminate bulkhead.

The absorbent material used in the water reservoir was solka floc BW-20. This material has absorption properties which are dependent upon the density to which it is compacted. The weight factor, defined as the ratio of pounds of water absorbed to the pounds of solka floc, decreases with increased density. Figure 1-10 shows curves of weight factor and volumetric efficiency as a function of density. However, the minimum density allowable for prevention of separation under vibration conditions was found by test to be 3.8 grams of solka floc per cubic inch. Thus, the design point became 3.8 grams per cubic inch and the corresponding weight factor of 3.2 pounds of water per pound of solka floc.

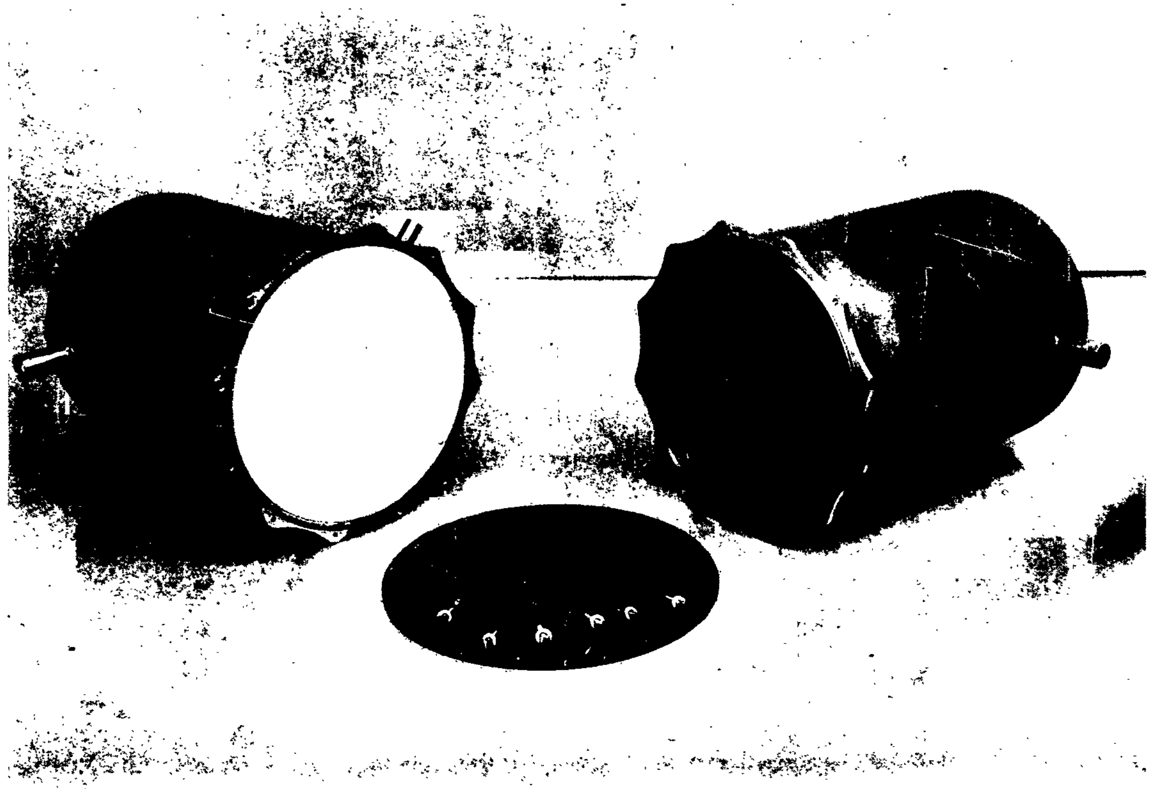


Figure 1-9. Water Storage Reservoir

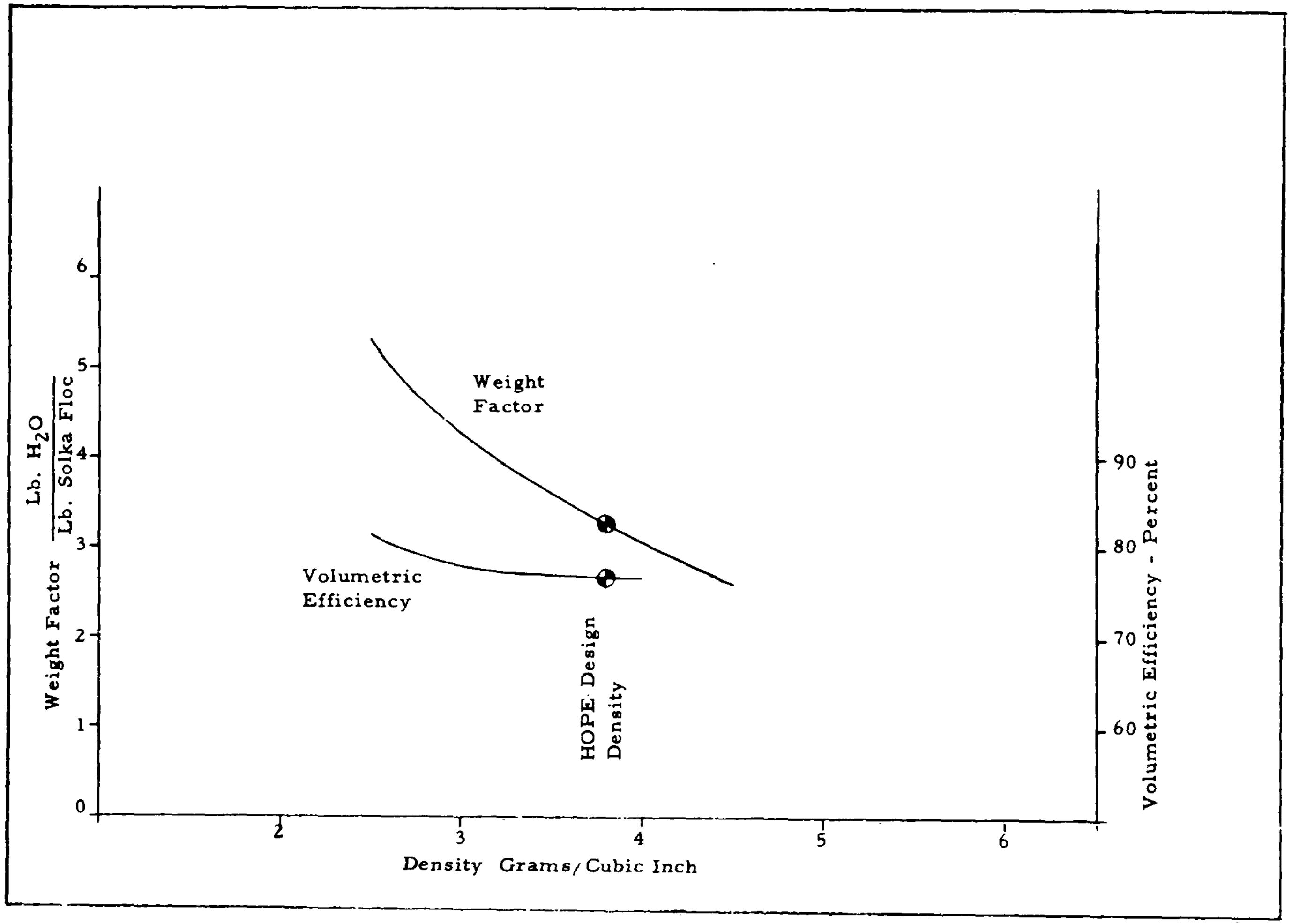


Figure 1-10. HOPE Water Storage Absorbent Weight Factor and Volumetric Efficiency vs. Density Solka Floc BW-20

The original water reservoir (Phase 1 Design) was sized to contain the product water from a 7-day mission at 25 watts. This can be calculated as follows:

$$\text{Water Production Rate} = W_{H_2O} = 0.934 \text{ lb. } H_2O/\text{KW hr.}$$

$$\frac{\text{Water Produced}}{\text{Module}} = 0.934 \frac{\text{lb. } H_2O}{\text{KW hr.}} \times 0.025 \text{ KW} \times 168 \text{ hr.} = 3.92 \text{ lb. } H_2O$$

$$\text{Req'd water tank volume} = 3.92 \text{ lb. } H_2O \times \frac{1.0 \text{ lb. Solka Floc}}{3.2 \text{ lb. } H_2O}$$

$$\times \frac{1.0 \text{ cu. in.}}{3.8 \text{ gm. Solka Floc}} \times \frac{453.6 \text{ gm.}}{1.0 \text{ lb.}}$$

Required Tank Volume = 146 cu. in.

Early in Phase I-a, it was decided to increase the water reservoir capacity by lengthening the tank. Each compartment of the tank could be lengthened 0.94 inches without causing interference with the shell of the capsule. The resulting tank capacity per module became 167 cu. in. giving a water capacity per module of:

$$\text{Water capacity} = 167 \text{ cu. in.} \times \frac{3.8 \text{ gm Solka Floc}}{1.0 \text{ cu. in.}} \times \frac{1.0 \text{ lb.}}{453.6 \text{ gm}}$$

$$\times \frac{3.2 \text{ lb. } H_2O}{1.0 \text{ lb. Solka Floc}}$$

Water capacity = 4.5 lb.

The lengthened tank design was adopted for the qualification systems. When the first qualification reservoir was completed, tests were run to determine its water capacity. Each half of the reservoir was tested separately, one with the bulkhead facing up and the other with it facing down to simulate their respective development test vehicle positions. Water was fed into each tank through its transport wick and flexible tube. The test setup is shown in Figure 1-11.

The results of the test, which are plotted in Figure 1-12, showed that the tanks will each absorb 4.75 lbs. of water. This is 5.5 per cent more than the design capacity.

1.3.4 Transport Wick Tube and Disconnect

The transport wick tube originally consisted of a section of Tygon tubing forced over straight fittings at the module and water storage tank. This design, which was marginal because of possible outgasing of the Tygon, was changed in Phase I-a to teflon-lined flexible hose assembly as pictured in Figure 1-13. The wick disconnect is located at the reservoir end of the transport tube. The threaded half of the disconnect is mounted on the tank. Figure 1-14 shows the transport wick tube assembly, disconnected from the reservoir. Figure 1-1 shows the tube connected to the module.

Figure 1-11. Test Setup - Water Tank Capacity Tests

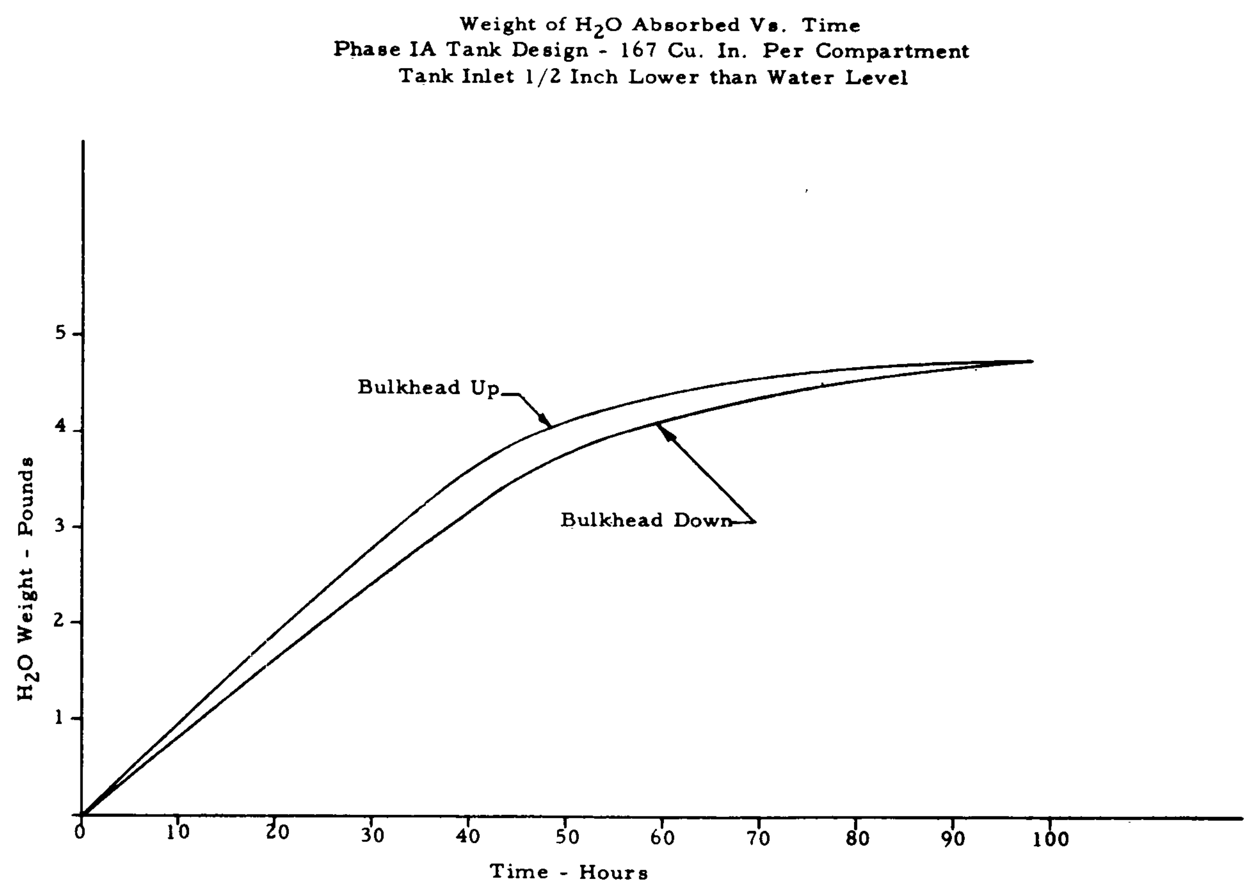


Figure 1-12. HOPE Water Reservoir Capacity Test

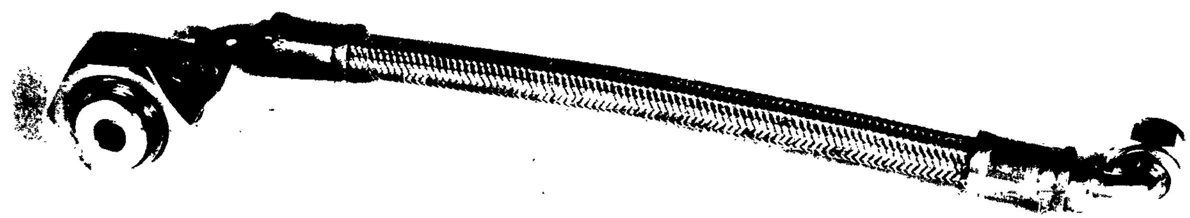


Figure 1-13. Transport Wick Hose Assembly

Figure 1-14. Transport Wick Tube, Wick Disconnect & Water Reservoir

In order to determine the difference in flow characteristics, a test was run simultaneously on two transport wicks with wick disconnects and one standard transport wick without a disconnect. Figure 1-15 shows the setup used for this test.

The results of these tests are shown in Figure 1-16. The weight flow rate through the standard transport wick stabilized at about .030 pounds per hour, but then rapidly decreased to a negligible flow after 200 hours. The transport wick with wick disconnect stabilized at about the same flow rate but continued to flow for 371 hours, at which time the test was discontinued.

The flow rates with and without the disconnect were only slightly above the rate at which water is produced in the fuel cell module.

Laboratory data obtained during Phase 1 indicated a flow capacity of .152 lb. per hour which is considerably higher than the later test results. Also, laboratory tests run on several wick disconnect configurations showed that the flow rate was hardly affected by the presence of the disconnect.

The reason for the large difference between the laboratory results and the results obtained from the prototype configuration was apparently the sharp bend in the transport wick at the entrance and exit of the tygon tube which tended to restrict flow. During the lab tests, the wick materials were not encased in wick tubes but instead were supported on 0.5 inch diameter lucite rods. Additional tests would be required to resolve this inconsistency in results.

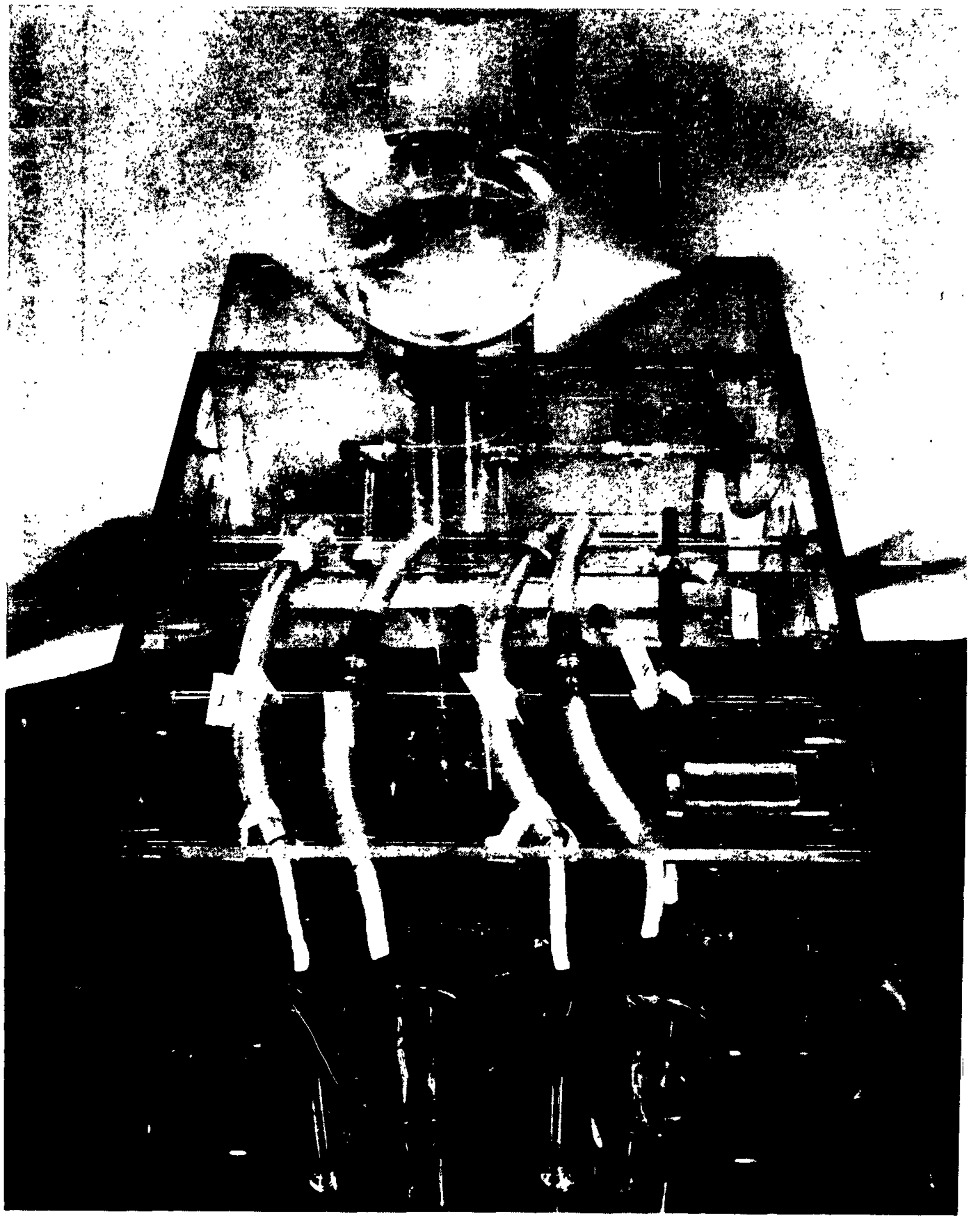


Figure 1-15. Test Setup - Transport Wick Flow Tests

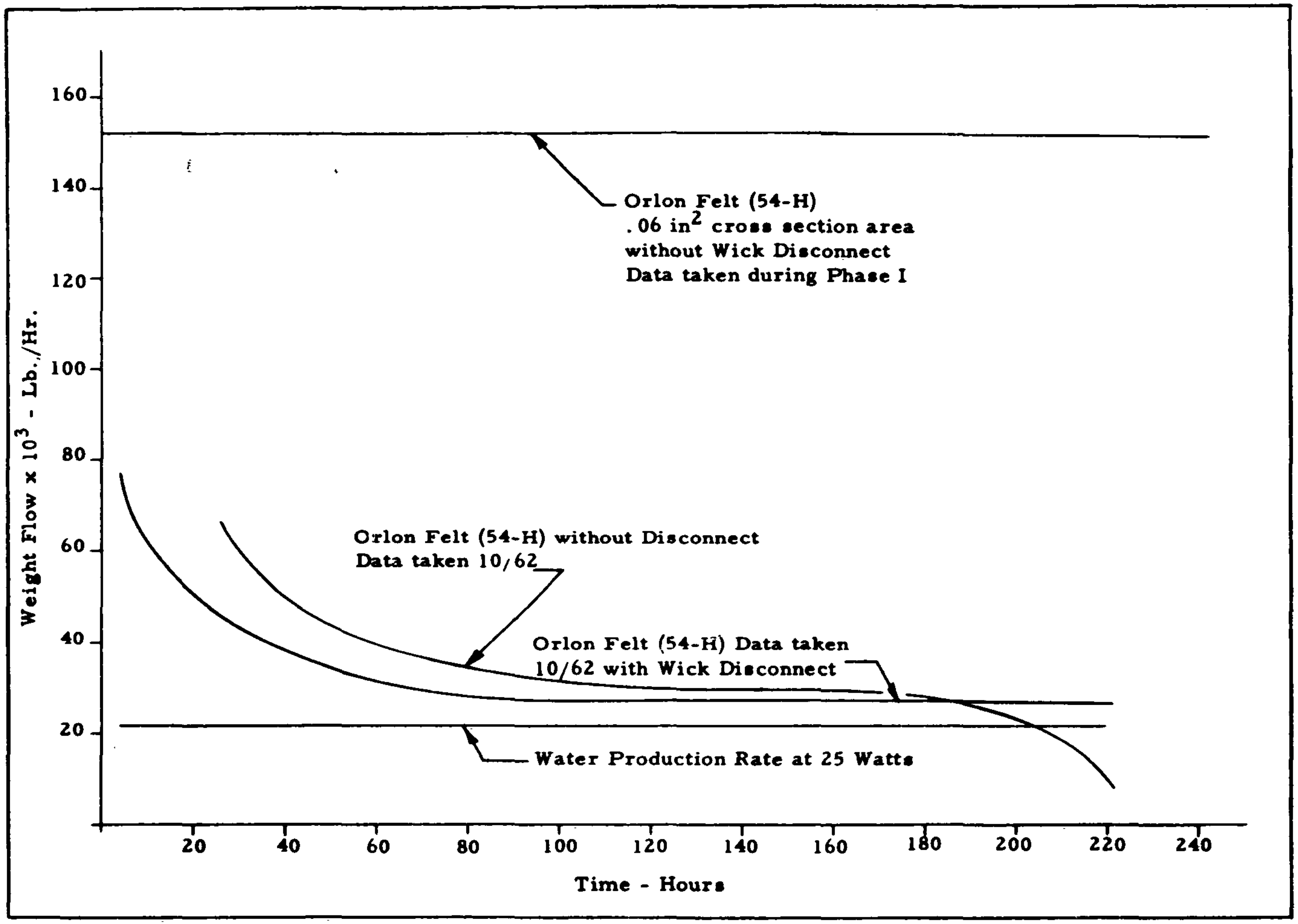


Figure 1-16. Water Transport Wick Performance with and without Wick Disconnect-Water Weight Flow vs. Time

1.4 HOPE Fuel Cell Operating Instructions

The operating and maintenance instructions for the fuel cell were written to assure proper handling of the fuel cell during subsequent storage, checkout, test vehicle installation, and subsequent qualification testing of the HOPE Spacecraft system.

The instruction booklet, which includes description, schematics, and trouble shooting techniques, is included in Appendix I-G.

1.5 HOPE Fuel Cell Reliability

An indication of the reliability of the HOPE fuel cell can be obtained by analyzing the data from tests on Polymer A-Prime Series D cells. All tests had been run within the temperature range of 90 to 110°F and at the current density of 11 amps per square foot.

A summary of all of the tests run on Series D is shown in the following chart.

No. Cells	Test Hours	Cell-Hours	Type of Failure
4	54	324	no failure
2	171	342	no failure
6	154	924	no failure
5	100	500	no failure
6	1801	10,806	no failure
4	6	24	no failure
35	168	10,885	no failure
35	81	2,835	no failure
35	48	1,680	no failure
132 Total	365	28,320 Total	
1	365	365	membrane leak

The following outlines the steps used to determine the reliability of HOPE fuel cell modules:

Step 1: Determine mean time between failures from data:

$$\text{MTBF} = \frac{\text{(number of failure-free cells)(number of operating hrs.)} + \text{(number of failed cells)(number of operating hours)}}{\text{number of failures}}$$

$$= \frac{(28,320) + (1)\ (365)}{1} = 28,685 \text{ hours}$$

Step 2: Determine failure rate λ

$$\lambda = \frac{1}{\text{MTBF}} = \frac{1}{28,685} = 3.48614 \times 10^{-5} \ \frac{\text{cell failures}}{\text{hour}}$$

$$\lambda = 3.486\ \%/1000 \text{ hours}$$

Assuming that the data is a true indication of failure and that the exponential law applies, the observed failure rate is 3.486%/1000 hours for an average stack.

$$\text{The average stack} = \frac{132 \text{ cells}}{9 \text{ stacks}} = 14.8 \text{ cells/stack}$$

On the basis of a 35 cell stack, the failure rate would be:

$$\frac{35}{14.8}\ (3.486\ \%/1000 \text{ hours}) = 8.25\%/1000 \text{ hours}$$

1.6 HOPE Fuel Cell in Orbit

The purpose of the HOPE fuel cell program was to develop a fuel cell power supply capable of operatinn in an orbiting capsule and then study its performance characteristics, by means of telemetered data while in orbit.

The primary consideration relative to space operation was whether or not the fuel cell and water removal system would function differently in an ambient of zero gravity.

1.6.1 Zero Gravity

During Phase 1-a some work was outlined in the analysis of zero gravity effects on the various phenomena existing within the system while it is operating.

Appendix I-J contains an analytical review of gravitational effects on ion exchange membrane fuel cells. The results of the analysis can be summarized as follows:

- Liquid films remain stable under zero-G.
- Meniscus level variations not known but can be investigated experimentally from electrode properties.
- Mass transport process is unaffected by zero-G.
- Interfacial water transport conditions unaffected by zero-G.
- Vibrational and stack effects should be investigated.

The conclusions drawn from this analysis is that many phenomena and processes associated with the operation of the fuel cell and its water removal and storage system should remain unaffected by zero-G. However, there are still unknown areas which can only be evaluated experimentally.

1.6.2 Failure Analysis

In order to analyze possible failures that may occur in orbit, it was necessary to study how the telemetered data would be evaluated. The following failure modes were studies:

- Accumulation of inert gases
- Internal hydrogen gas leaks
- Loss of radiator cooling
- Flooded hydrogen electrode
- Flooded oxygen electrode
- Increase of contact resistance
- Transport wick failure

Part II of the zero gravity discussion, which is included in Appendix I-J, shows how each of these failure modes would be signaled, what action would be initiated, and what analysis would result. Since only preliminary work on failure analysis was accomplished, a more thorough study including induced failure testing was recommended for Phase II of the program.

1.7 Program Status at Termination

The HOPE program was terminated by ASD on October 18, 1962. The exact status of activities can be summarized as follows:

ACTIVITY	STATUS
Development Testing	
a. Controller Compatibility	Complete
b. Performance Stability	Complete
c. Simulated Bench Test	Complete
d. 30 PSIA Operation	Postponed until DTV test at Spacecraft Department
Qualification System Manufacture	
a. Manufacture Cell Assemblies	Approx. 80 complete
b. Module Hardware	Complete for 3 modules
c. Module Assemblies	2 assembled (Q-1 & Q-2) 1 tested (Q-1)
d. Water Reservoir Assemblies	2 assembled - 1 tested
Fuel Cell Operating Instructions	Rough Draft Complete

SECTION 2

FUEL CELL CONTROL SUBSYSTEM

R. Luck

D. Tasca

2.0 FUEL CELL CONTROL SUBSYSTEM

2.1 FUEL CELL CONTROL FUNCTION REQUIREMENTS AND CIRCUIT DESIGN STATUS

Although the broad functions to be performed by the Fuel Cell Controller (FCC) have not changed since its original conception, the detailed operations developed to implement these functions were revised considerably.

The finalized purge sensing and control functions are as follows:

- Purge Control to be activated when a group of two cells reaches an undervoltage condition of 1.5 volts or any one of the 11 groups of three cells reaches an undervoltage condition of 2.25 volts for at least one-half second.
- $H_2/0_2$ combination purges to be continued until the cell group voltage recovers to 1.56 volts for a 2-cell group and 2.35 volts for a 3-cell group.
- Purge Control to activate a combination H_2-vent/0_2-flush purge every two hours, automatically, as a "preventative maintenance" measure.
- Minimum delay time between purges to be 15 seconds.
- Undervoltage activated purges to be limited to a maximum of 3 per 2-hour period, which combined with the one timer activated purge every 2 hours will result in a maximum of 4 per 2-hour period.
- Purge Control to be initiated by energizing, simultaneously, both the normally open H_2 supply valve and the normally closed H_2 purge valve for 1 second to provide an H_2 vent purge and by energizing the normally closed 0_2 purge valve for 15 seconds to provide an 0_2 flush purge.
- H_2 vent purge valves to be de-energized when the differential pressure across the fuel cell membrane is such that $P_0 > P_H$ by $2.5 \begin{smallmatrix}+0.5 \text{ psi} \\ -0 \text{ psi}\end{smallmatrix}$ and to be re-energized when the differential pressure reduces to $2.3 \begin{smallmatrix}+0 \text{ psi} \\ -0.3 \text{ psi}\end{smallmatrix}$.
- 0_2 flush purge valve to be de-energized when the differential pressure across the fuel cell membrane is such that $P_H > P_0$ by $1.5 \begin{smallmatrix}+0 \text{ psi} \\ -0.5 \text{ psi}\end{smallmatrix}$ and to be re-energized when the differential pressure reduces to $1.4 \begin{smallmatrix}+0 \text{ psi} \\ -0.4 \text{ psi}\end{smallmatrix}$.

The temperature sensing and control functions have been revised to exclude the $180^{\circ}F$ fuel supply shutoff requirement. The finalized temperature control functions are as follows:

- Telemetry and/or dummy spacecraft electrical loads to be cutoff if 2 out of 3 temperature sensing thermistors indicate a fuel cell over-temperature condition greater than $140^{\circ}F$.

- Telemetry and/or dummy spacecraft electrical loads to be reconnected when 2 out of 3 thermistors indicate a return to normal temperature of 125° or lower.

The fuel supply shutoff control is now on a gross undervoltage basis instead of a high overtemperature basis ($\sim 180^{\circ}F$). This change of the sensing mode requires an additional unit, the Fuel Supply Shutoff Controller. The finalized fuel shutoff sensing and control function is as follows:

- Fuel Supply Shutoff to be initiated when either one of the two groups of 4 cells reaches an undervoltage condition of 2.2 volts or when any one of the 9 groups of 3 cells reaches an undervoltage condition of 1.4 volts.

- H_2 and 0_2 fuel supply latch valve close solenoids to be energized for 1 second to shutoff the fuel supply.

- No re-engagement to fuel supply to be provided in space flight.

- Complete electrical disconnect of the fuel cell to be provided if fuel supply shutoff occurs during ground test only.

Power to operate the valves is drawn from the flight battery. Power to operate the control electronics is drawn from the associated fuel cell. Power to operate the fuel cell electrical disconnects is drawn from ground power supplies.

During this reporting period, the FCC circuit designs were modified to incorporate the changes to the purge sequencing mentioned above. Also, the fuel supply shut-off controller and the differential pressure override circuits were designed. Packaging design of the FCC was completed, while only a preliminary design of the fuel supply shutoff controller was completed. Appendix 2A includes detailed design calculations for the electronic subsystems.

2.2 DESCRIPTION OF CIRCUIT OPERATION FOR FUEL CELL CONTROL ELECTRONICS

2.2.1 Fuel Cell Controller

The detailed descriptions of the operation of the individual FCC circuits have for the most part remained the same. The differences in circuitry to implement the finalized functions are described in the paragraphs below. The overall schematic is shown in Figure 2-1, the function diagram in Figure 2-2, and the internal wiring diagram in Figure 2-3.

2.2.1.1 Purge Voltage Sensing, Temperature Sensing and Control, and Series Regulator

These circuits have not been significantly changed since the last report. The total module voltage sensor is no longer used to initiate a purge. However, the circuit is retained since a module undervoltage sensor and power control function is required for power source selection. The $180^{\circ}F$ temperature sensors and their associated control function have been eliminated. There was no change to the series regulator.

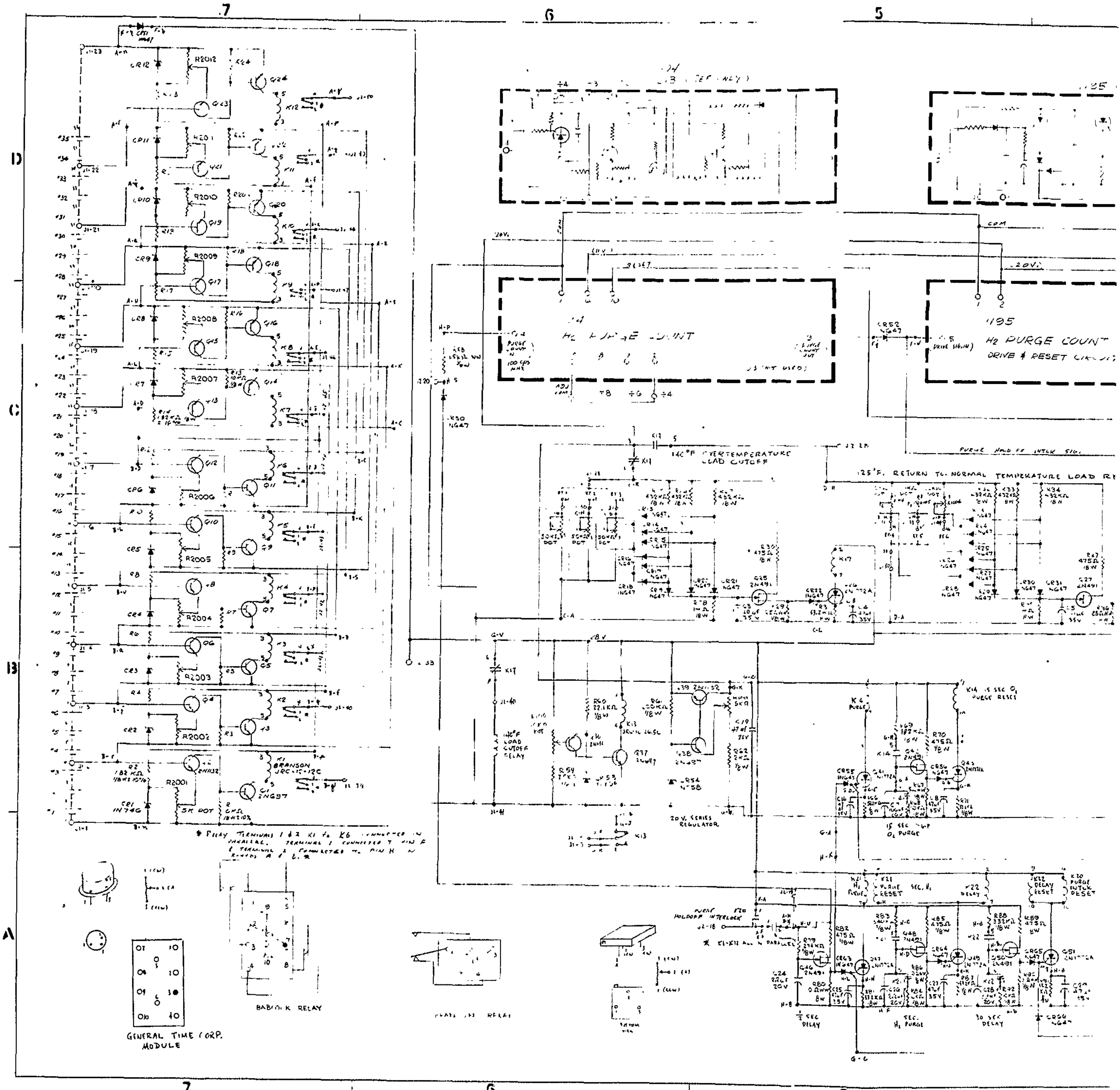
2.2.1.2 Purge Sequence and Control

The modification of the purge format has necessitated minor modifications to the interconnection and to the number of individual purge sequence and control circuits, but not to their basic operation. Because of the requirement for a 1 second H_2 vent purge and a 15 second 0_2 flush purge, separate timing circuits were required.

The original 15-second delay was extended to 30 seconds in order to meet the 15-second minimum time between purges. Also the 2-hour timer output signal was utilized to gate an $H_2/0_2$ purge automatically every two hours.

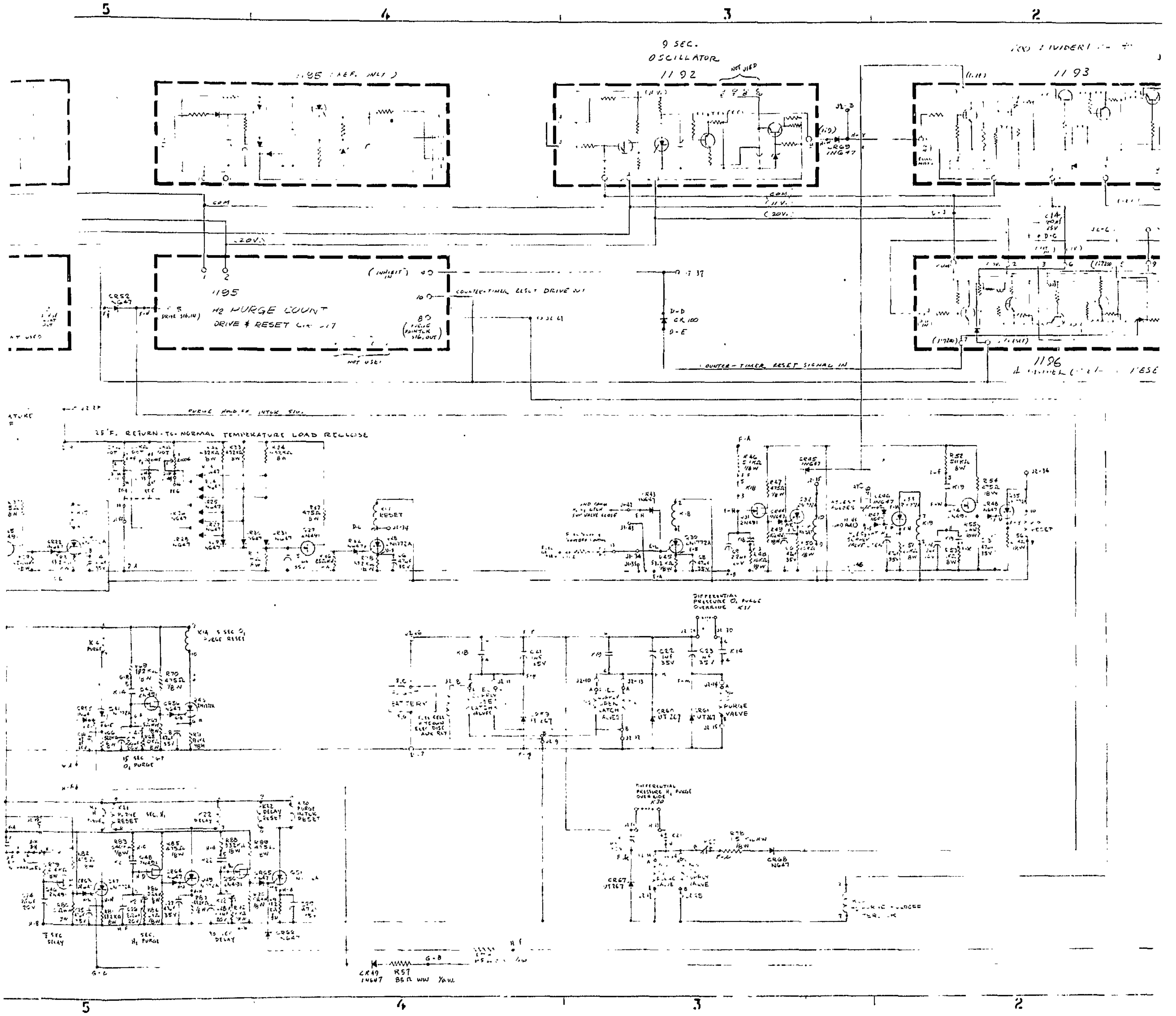
2.2.1.3 Differential Pressure Purge Override

During fuel cell purging if the differential pressure across the membrane rises above a certain level, the membrane will be permanently damaged due to rupture or edge separation. The differential pressure purge override circuit (DPPO) prevents the differential pressure across the membrane from exceeding the prescribed safetly limits which are 2.5 psi (H_2 below 0_2) and 1.5 psi (0_2 below H_2). The DPPO accomplishes this by de-energizing the hydrogen and oxygen purge valves, allowing the pressure to return to within normal limits.



H2 PURGE COUNT
H2 PURGE COUNT DRIVE & RESET CIRCUIT
140°F OVERTEMPERATURE LOAD CUTOFF
125°F. RETURN TO NORMAL TEMPERATURE LOAD RE
20V. SERIES REGULATOR
GENERAL TIME CORP. MODULE
BABCOCK RELAY
BRANSON
15 SEC O2 PURGE
SEC. H2 PURGE
30 SEC DELAY

1


5
4
3
2
9 SEC.
OSCILLATOR
1192
NOT USED
1193
1195
H2 PURGE COUNT
DRIVE & RESET
COUNTER-TIMER RESET DRIVE IN
COUNTER-TIMER RESET SIGNAL IN
1196
(20V.)
COM
35°F. RETURN-TO-NORMAL TEMPERATURE LOAD RECLOSE
BATTERY
PURGE VALVE
CR52
CR49
R57

2

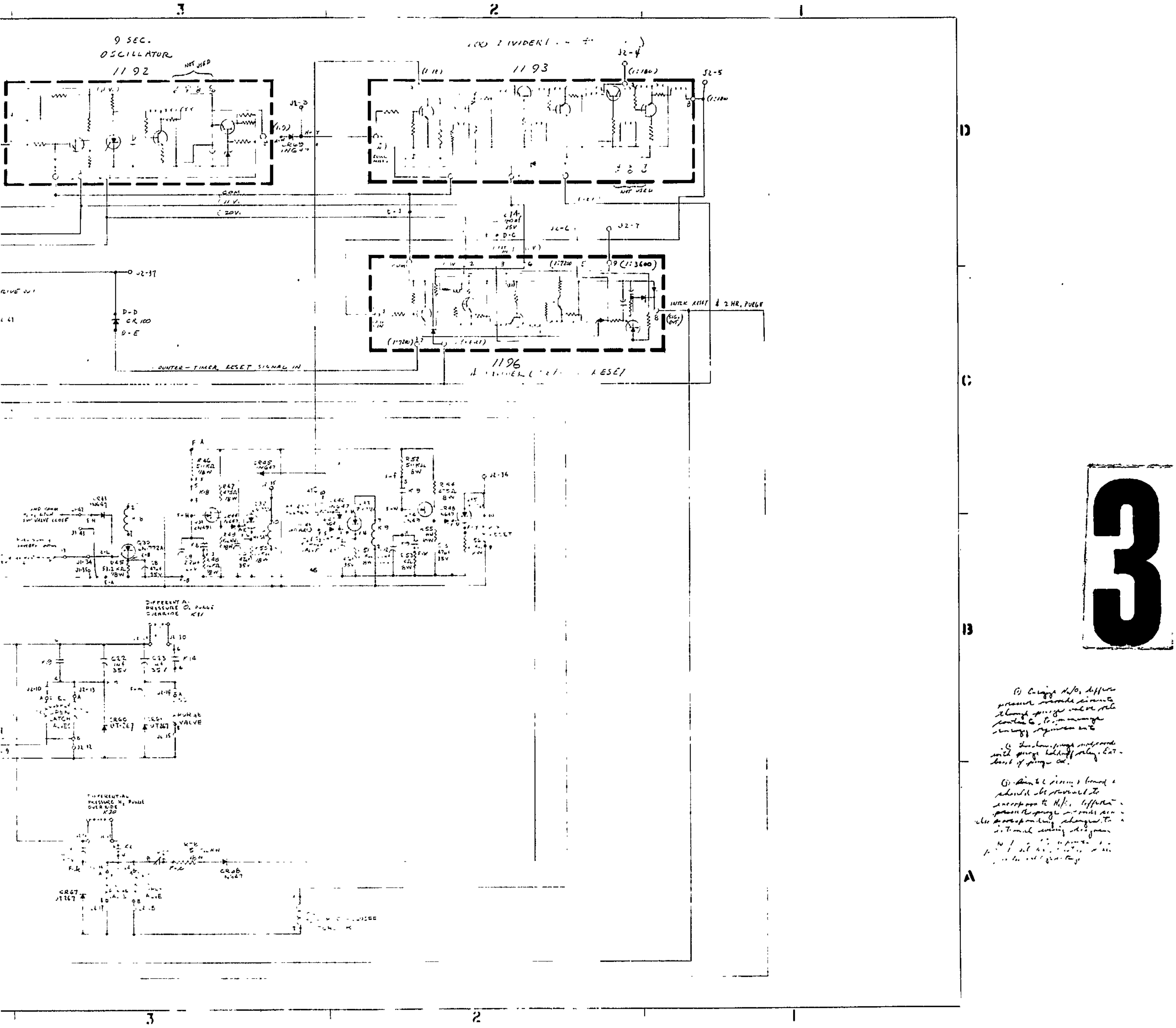
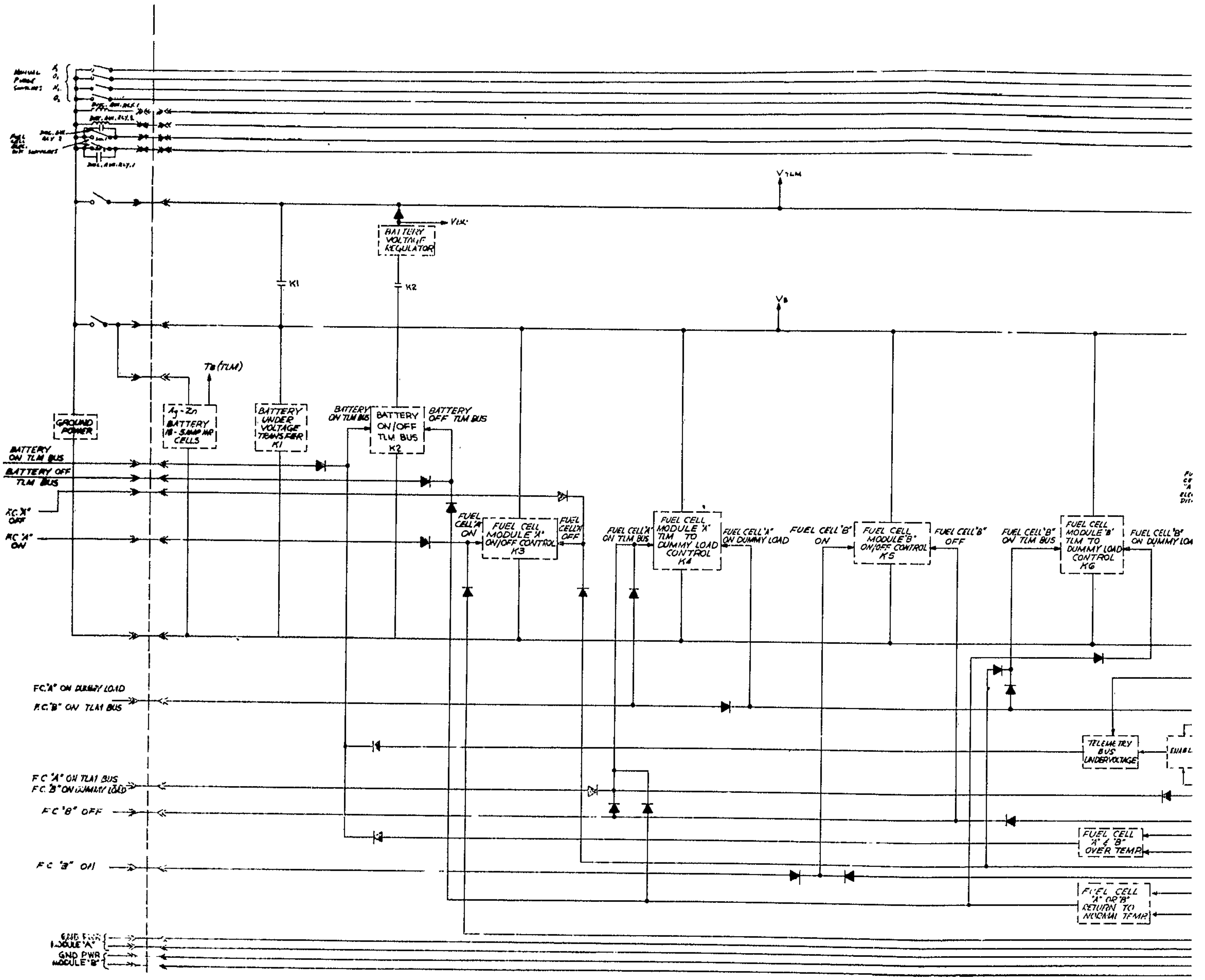
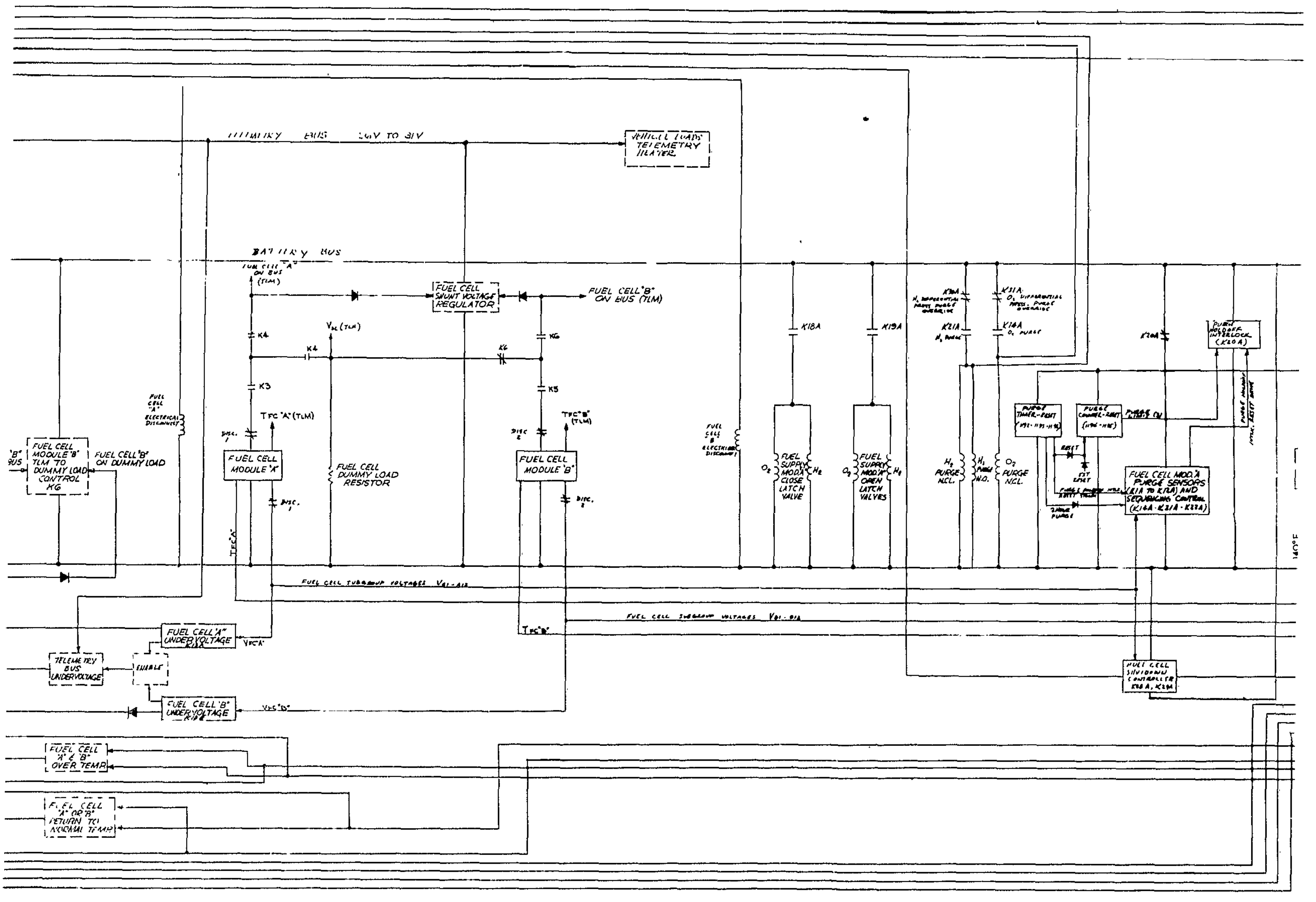


Figure 2-1. Fuel Cell Controller Schematic

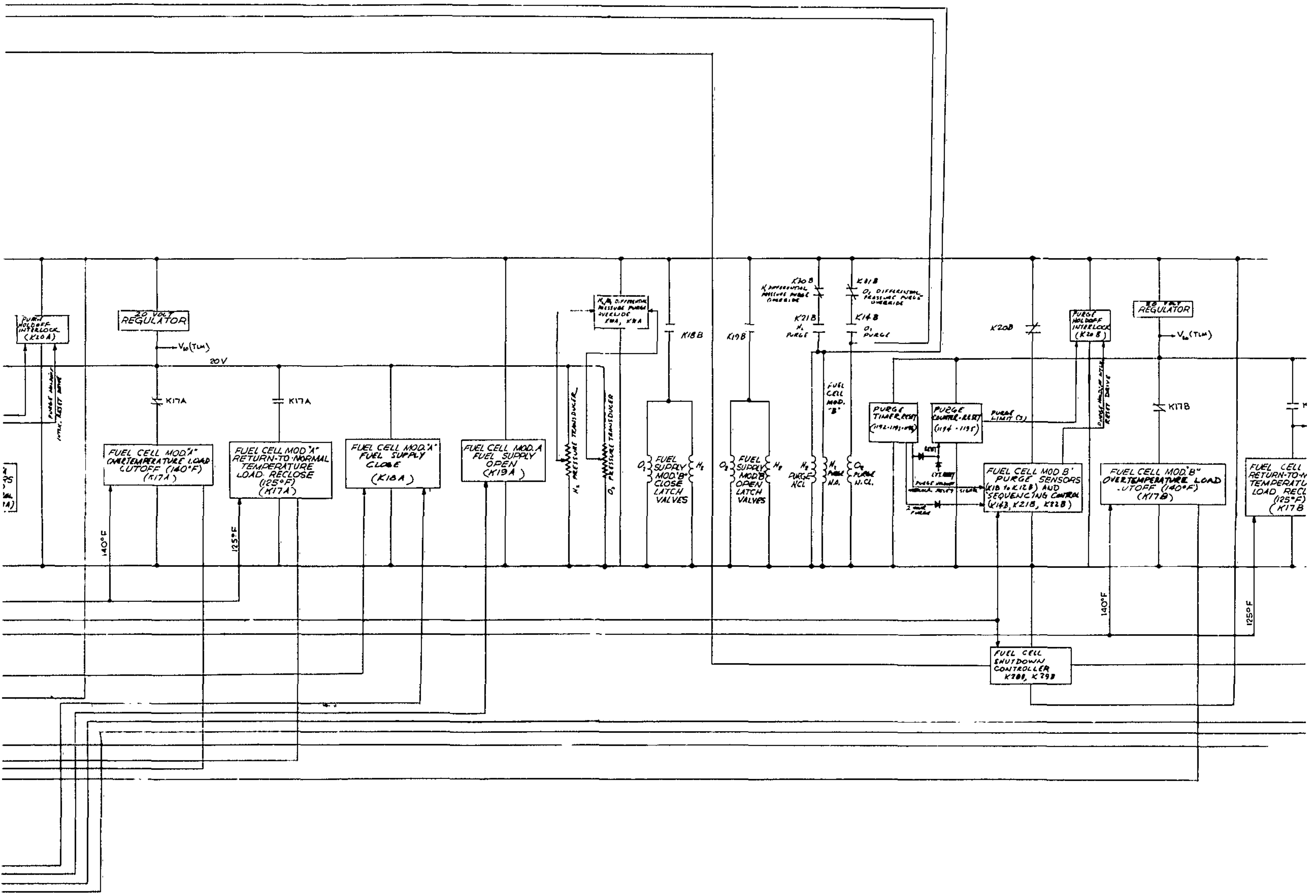


V TLM
BATTERY VOLTAGE REGULATOR
K1
K2
VB
TB (TLM)
GROUND POWER
Ag-Zn BATTERY 18-5AMP HR CELLS
BATTERY UNDER VOLTAGE TRANSFER K1
BATTERY ON TLM BUS
BATTERY ON/OFF TLM BUS K2
BATTERY OFF TLM BUS
BATTERY ON TLM BUS
BATTERY OFF TLM BUS
F.C."A" OFF
F.C."A" ON
FUEL CELL "A" ON
FUEL CELL MODULE "A" ON/OFF CONTROL K3
FUEL CELL "A" OFF
FUEL CELL "A" ON TLM BUS
FUEL CELL MODULE "A" TLM TO DUMMY LOAD CONTROL K4
FUEL CELL "A" ON DUMMY LOAD
FUEL CELL "B" ON
FUEL CELL MODULE "B" ON/OFF CONTROL K5
FUEL CELL "B" OFF
FUEL CELL "B" ON TLM BUS
FUEL CELL MODULE "B" TLM TO DUMMY LOAD CONTROL K6
FUEL CELL "B" ON DUMMY LOAD
F.C."A" ON DUMMY LOAD
F.C."B" ON TLM BUS
TELEMETRY BUS UNDERVOLTAGE
F.C."A" ON TLM BUS
F.C."B" ON DUMMY LOAD
F.C."B" OFF
FUEL CELL "A" & "B" OVER TEMP.
F.C."B" ON
FUEL CELL "A" OR "B" RETURN TO NORMAL TEMP.
GND PWR MODULE "A"
GND PWR MODULE "B"

1


BATTERY BUS
FUEL CELL "A" ON BUS (TLM)
FUEL CELL SHUNT VOLTAGE REGULATOR
FUEL CELL "B" ON BUS (TLM)
VEHICLE LOADS TELEMETRY HEATER
K4
K3
K5
K6
K18A
K19A
K21A
K20A
FUEL CELL MODULE "A"
FUEL CELL MODULE "B"
FUEL CELL DUMMY LOAD RESISTOR
FUEL CELL MODULE "B" TLM TO DUMMY LOAD CONTROL K6
FUEL CELL "B" ON DUMMY LOAD
FUEL SUPPLY MOD "A" CLOSE LATCH VALVE
FUEL SUPPLY MOD "A" OPEN LATCH VALVES
H_2 PURGE N.C.
H_2 PURGE N.O.
O_2 PURGE N.C.
PURGE TIMER-RESET
PURGE COUNTER-RESET
PURGE HOLDOFF INTERLOCK (K20A)
FUEL CELL MOD. "A" PURGE SENSORS (K1A TO K12A) AND SEQUENCING CONTROL (K16A-K21A-K22A)
FUEL CELL SHUTDOWN CONTROLLER
FUEL CELL SUBGROUP VOLTAGES
FUEL CELL "A" UNDERVOLTAGE
FUEL CELL "B" UNDERVOLTAGE
TELEMETRY BUS UNDERVOLTAGE
ENABLE
FUEL CELL "A" & "B" OVER TEMP
FUEL CELL "A" OR "B" RETURN TO NORMAL TEMP

2



20 VOLT REGULATOR
FUEL CELL MOD "A" OVERTEMPERATURE LOAD CUTOFF (140°F) (K17A)
FUEL CELL MOD "A" RETURN-TO-NORMAL TEMPERATURE LOAD RECLOSE (125°F) (K17A)
FUEL CELL MOD "A" FUEL SUPPLY CLOSE (K18A)
FUEL CELL MOD. A FUEL SUPPLY OPEN (K19A)
FUEL SUPPLY MOD "B" CLOSE LATCH VALVES
FUEL SUPPLY MOD "B" OPEN LATCH VALVES
PURGE TIMER RESET
PURGE COUNTER RESET
FUEL CELL MOD B' PURGE SENSORS (K1B to K12B) AND SEQUENCING CONTROL
FUEL CELL MOD "B" OVERTEMPERATURE LOAD CUTOFF (140°F) (K17B)
FUEL CELL SHUTDOWN CONTROLLER K28B, K29B
PURGE HOLDOFF INTERLOCK (K20B)
REGULATOR
K17A
K17B
K18B
K19B
K20B
K21B
K14B
20V
140°F
125°F

3

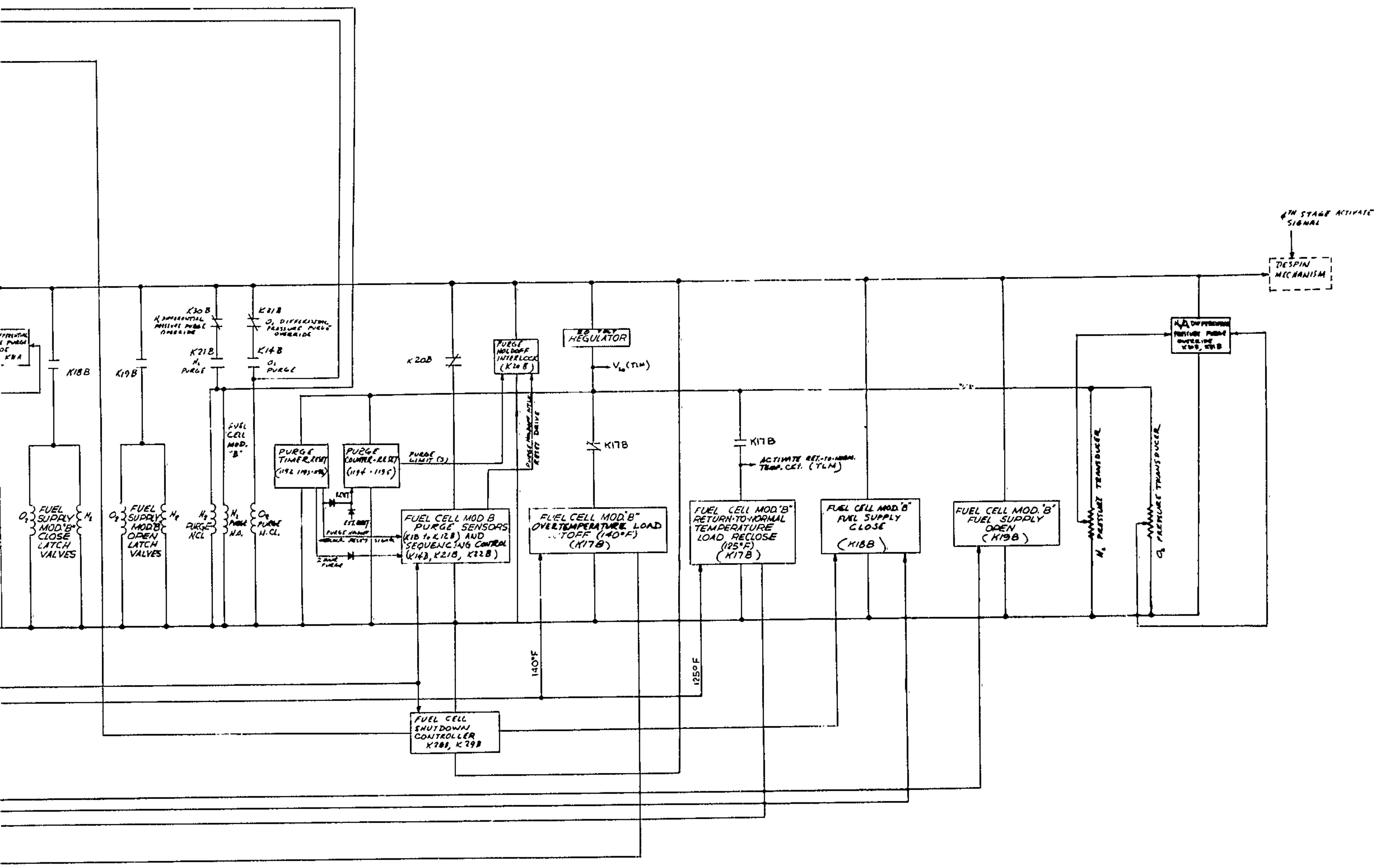
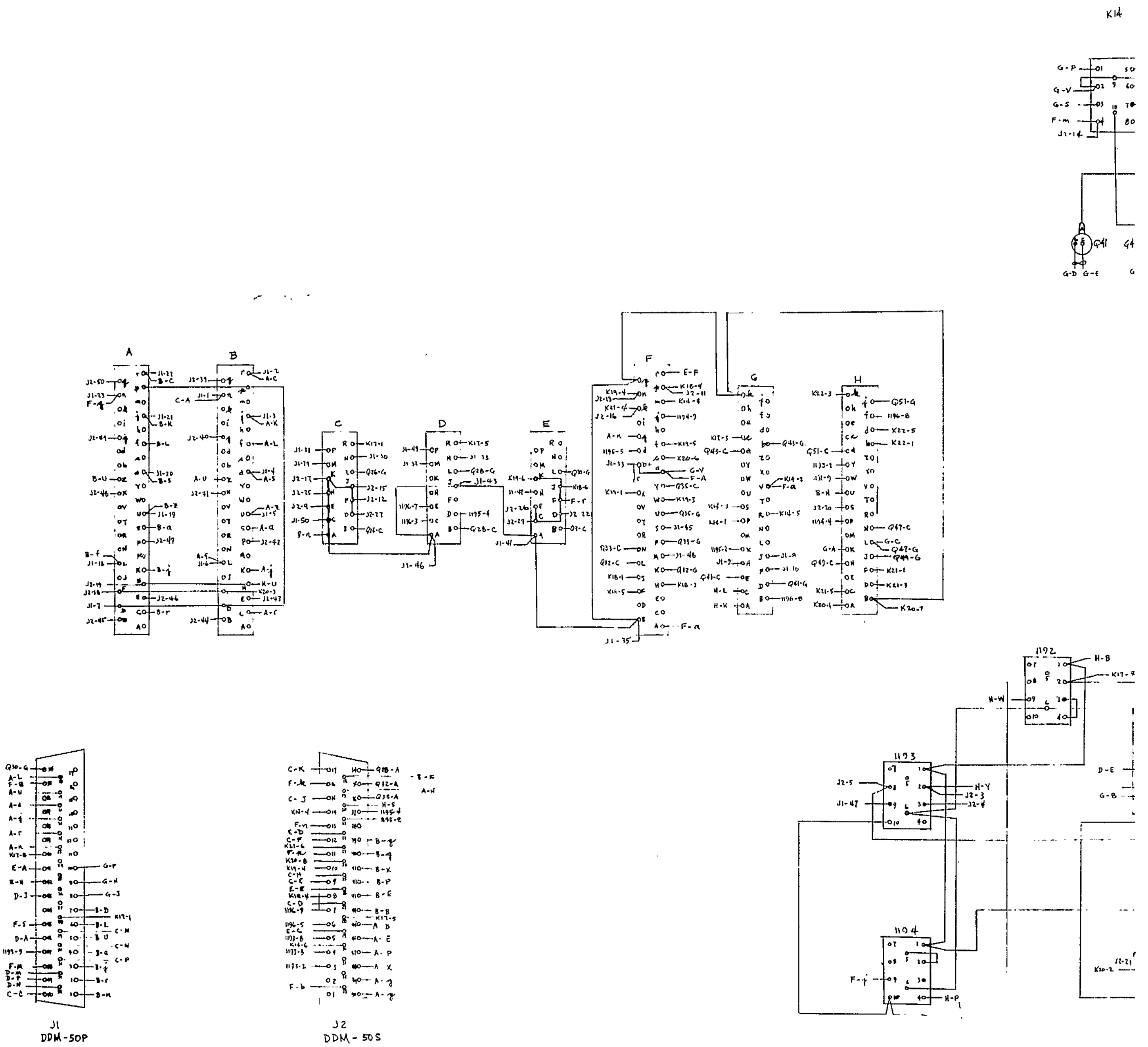
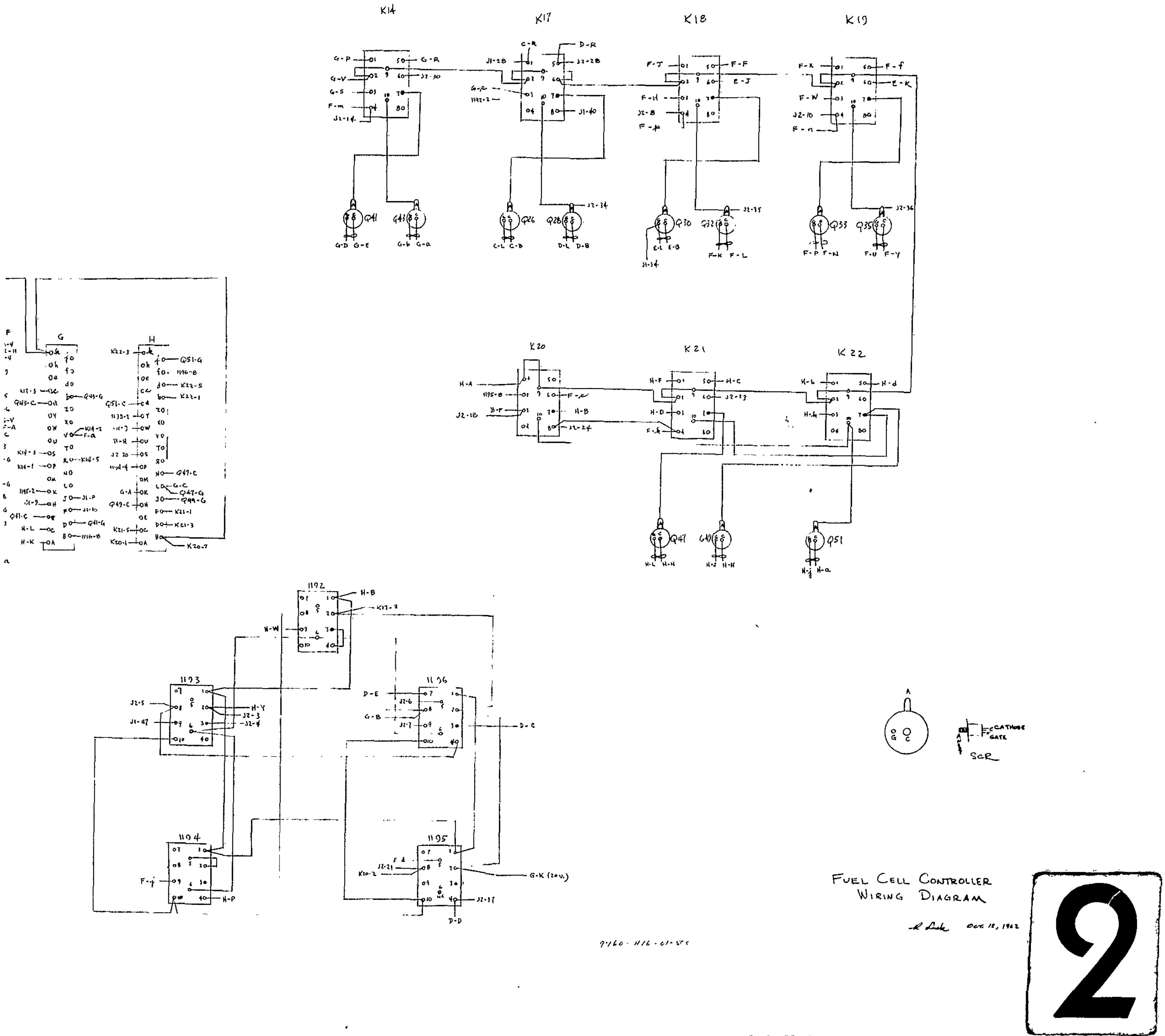


Figure 2-2. Fuel Cell Controller Schematic



1



2

Figure 2-3. Fuel Cell Controller Wiring Diagram

The H_2 and 0_2 pressures are sensed by a standard potentiometer transducer shown in Figure 2-4 . If a regulated 20-volt supply is connected across the transducer with negligible load from wiper to ground, a linear pressure-voltage curve as shown in Figure 2-5 will be generated.

The DPPO consists of two Darlington emitter followers (Figure 2-6) across each transducer wiper to ground for impedance buffering. This puts a load of 320K across the transducer output to approximate a no-load condition. The operating points on the pressure-voltage curves are sensed across the 200 Ω buffer resistors and applied by adjusting potentiometers. The signals are connected to sensing transistors which apply signals to the appropriate relay amplifier to deactivate the purge valve on the low pressure side.

The function diagram of the DPPO is shown in Figure 2-6, and the circuit diagram in Figure 2-7.

An alternate scheme, which was not fully evaluated in this reporting period, is shown in Figure 2-8 . The output of each pressure transducer is sent to a differential amplifier through an impedance matching stage. The output from each side of the differential amplifier is applied through another buffer stage. The output from each side of the differential amplifier is applied through its isolation amplifier to a relay amplifier which de-energizes the purge valves.

2.2.2 Fuel Supply Shutoff Controller (FSSC)

The schematic diagram of the FSSC is shown on Figure 2-9. A voltage of 1.4 volts for a group of 3 cells and 2.2 volts for a group of 4 cells indicates a defective module which, if allowed to continue to supply electrical energy, may cause rapid expenditure of fuel. The FSSC is designed to detect a defective module by sensing the corresponding cell voltages and disconnecting the fuel supply from the module for the remainder of the flight. In ground testing, the complete electrical load is removed from the fuel cell by automatically energizing its associated 36-pole single throw electrical disconnect relay through the relay switch of the FSSC. The FSSC utilizes the series connection of 35 individual cells by dividing the fuel cell module into nine groups of 3 cells and two groups of 4 cells. The FSSC consists of 11 voltage sensors, 9 to sense a voltage of 1.4 volts of a group of 3 cells and 2 to sense a voltage of 2.2 volts of a group of 4 cells. The FSSC is similar to the fuel cell controller (FCC) voltage sensor in that their voltage sensing elements are common emitter stages with the emitters clamped at a zener reference, Figure 2-10. But unlike the FCC voltage sensors whose outputs energize individual relay switches, the outputs of the bottom 6 FSSC voltage sensors are connected to form an "or" gate input to a single relay switch (Figure 2-11), while the top 5 FSSC voltage sensors are connected to form an "or" gate input to another relay switch. The two "or" gates are complementary circuits in order to provide the necessary collector and zener reference supply voltage levels.

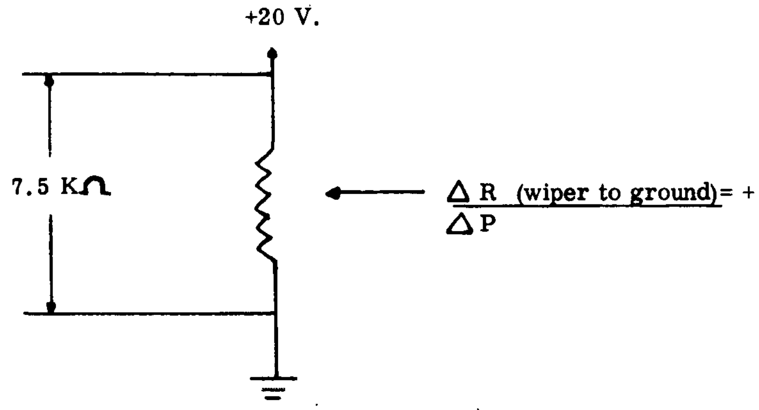


Figure 2-4. Standard Potentiometer Transducer

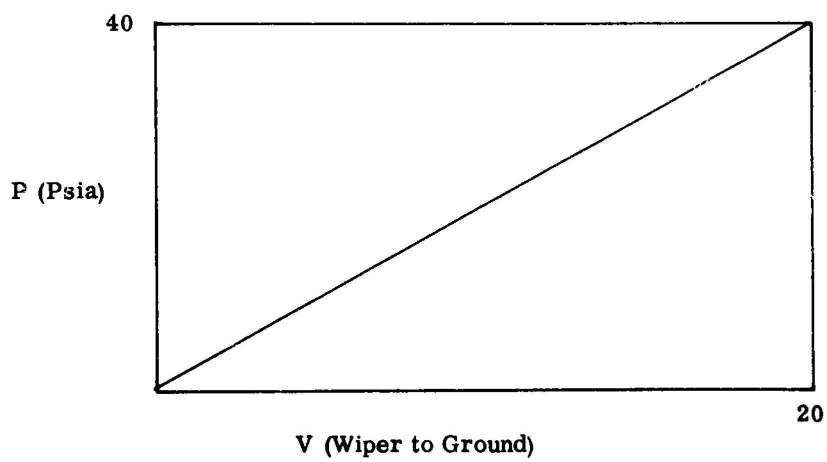


Figure 2-5. Linear Pressure-Voltage Curve

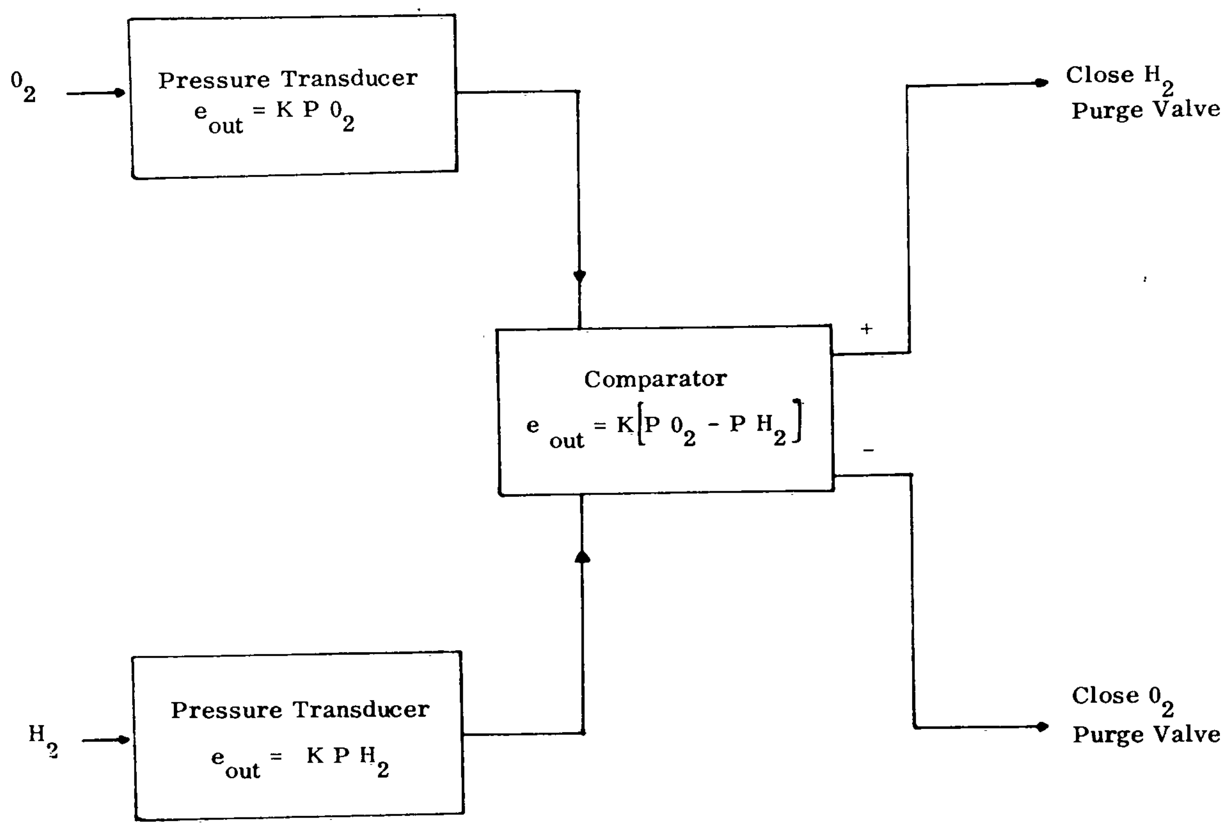


Figure 2-6. DPPO Function Diagram

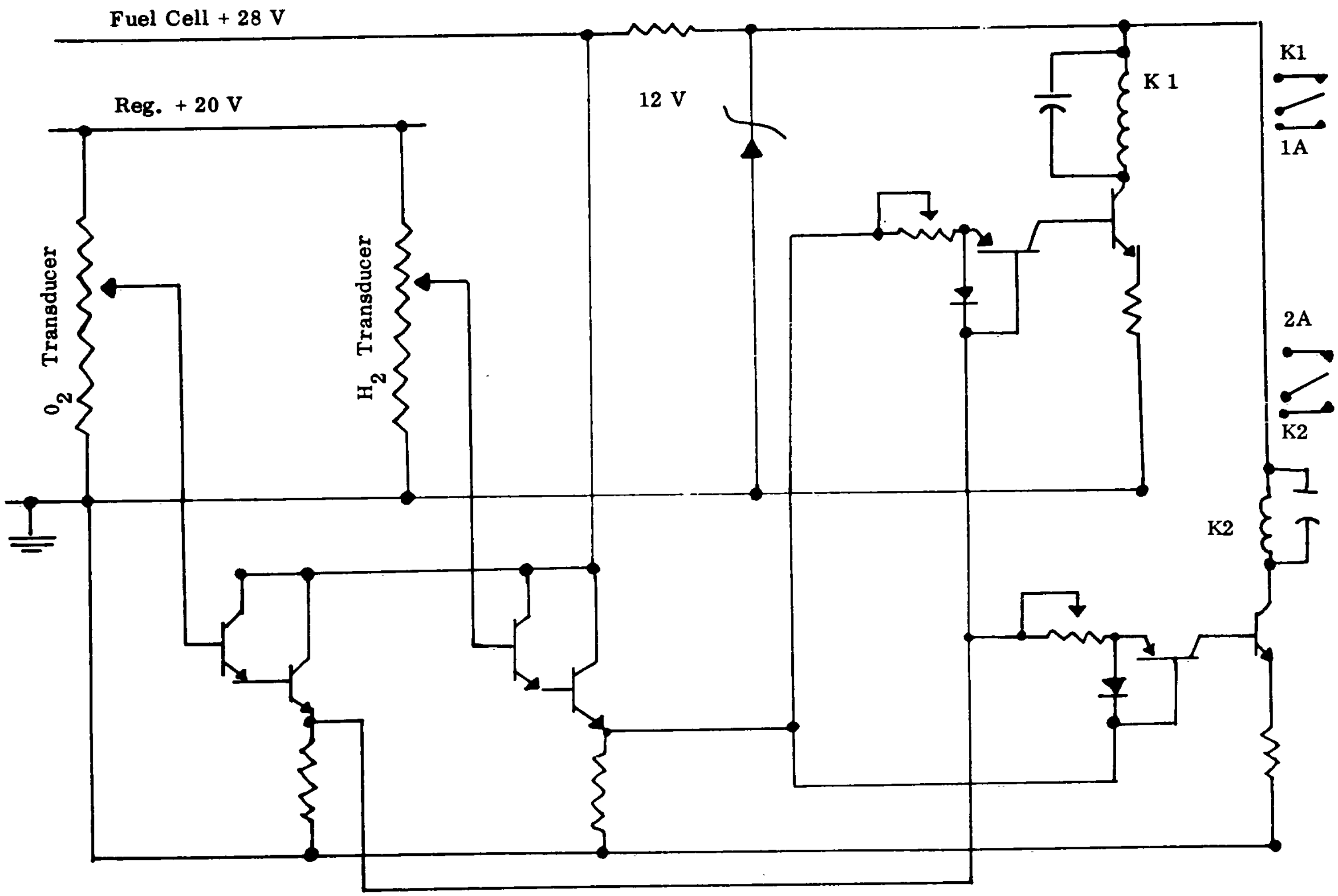


Figure 2-7. DPPO Circuit Diagram

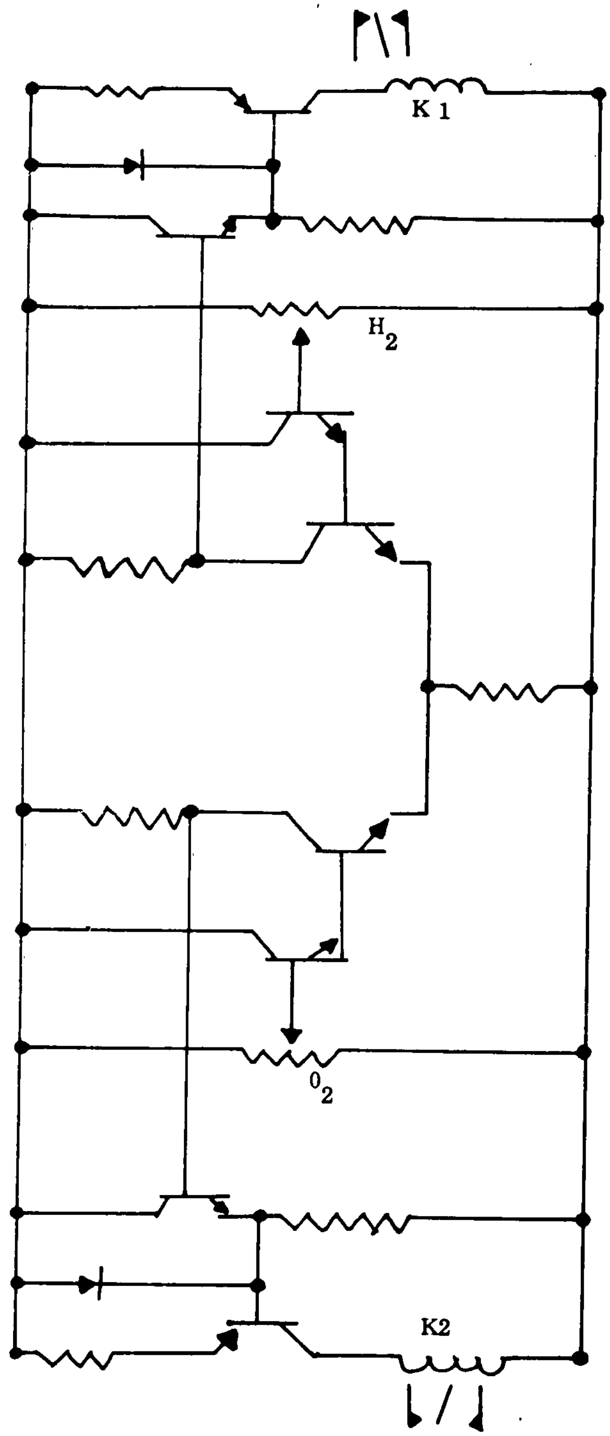
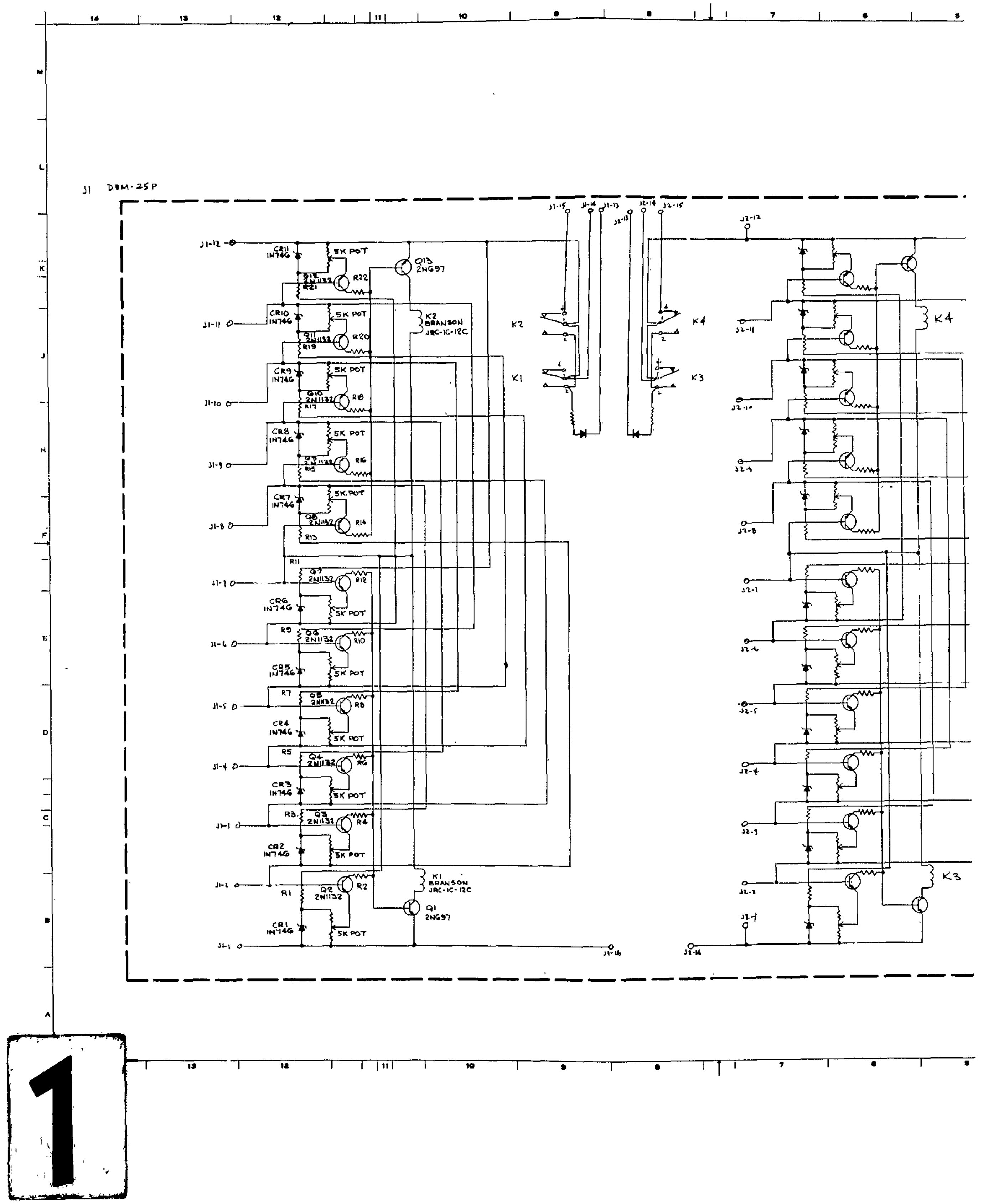


Figure 2-8. Alternate DPPO Circuit



J1 DBM-25P
K1
K2
K3
K4
Q13
2N697
Q1
2N697
K2
BRANSON
JRC-1C-12C
K1
BRANSON
JRC-1C-12C
5K POT
IN746
2N1132
J1-16
J2-16
1

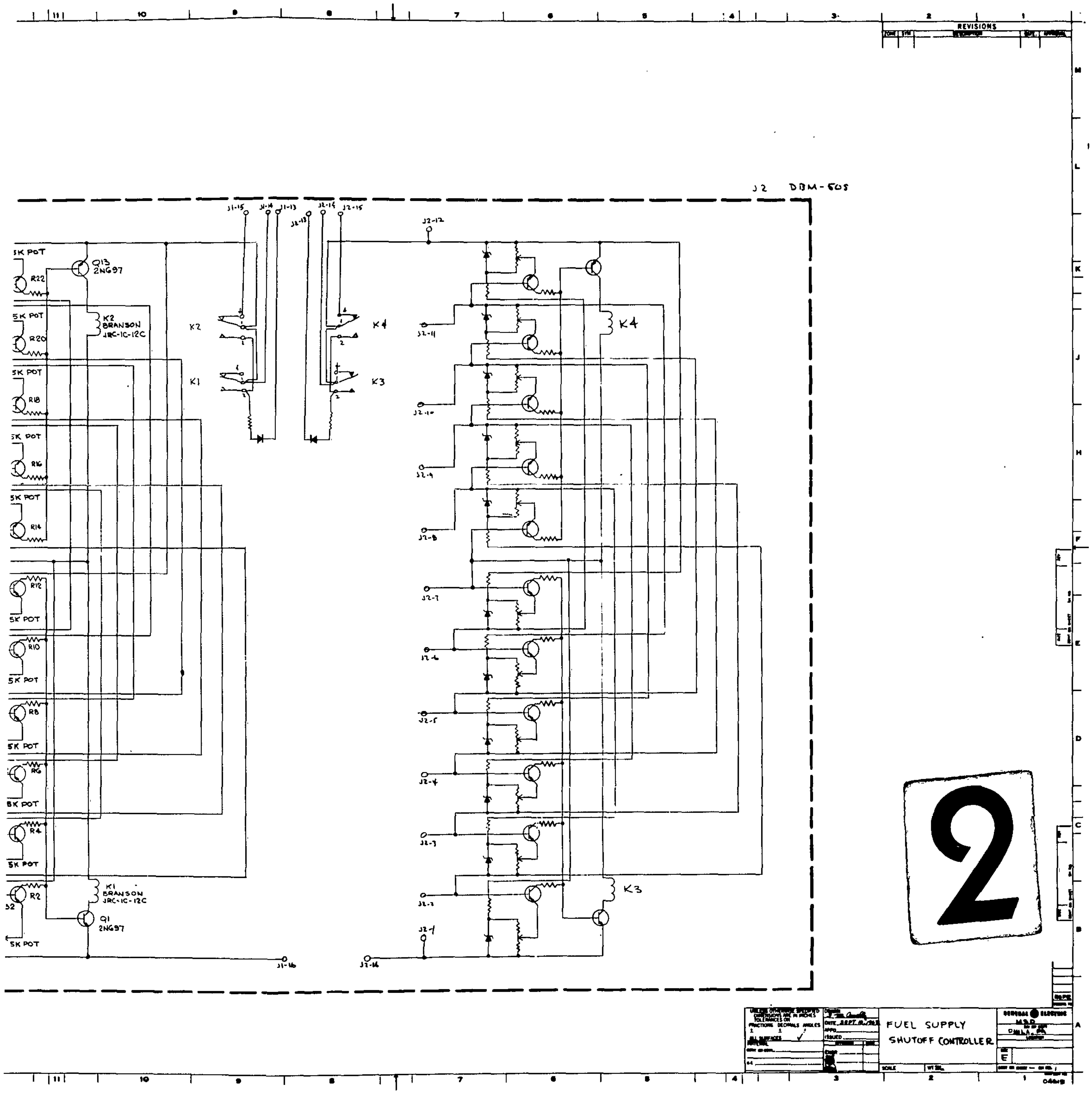
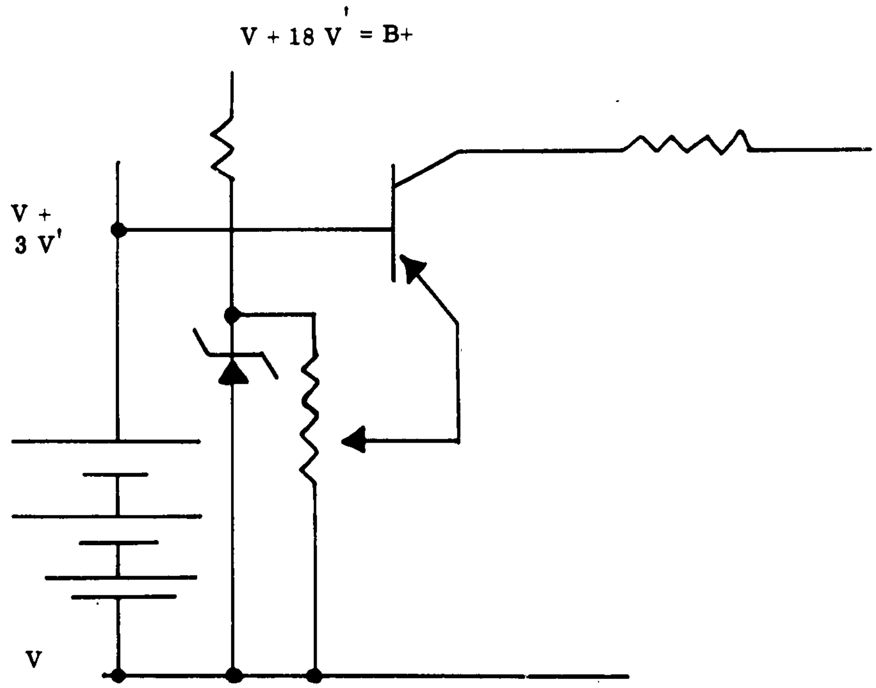


Figure 2-9. Fuel Supply Shutoff Controller



V' = Normal Cell Voltage

Figure 2-10. FSSC Voltage Sensing Element

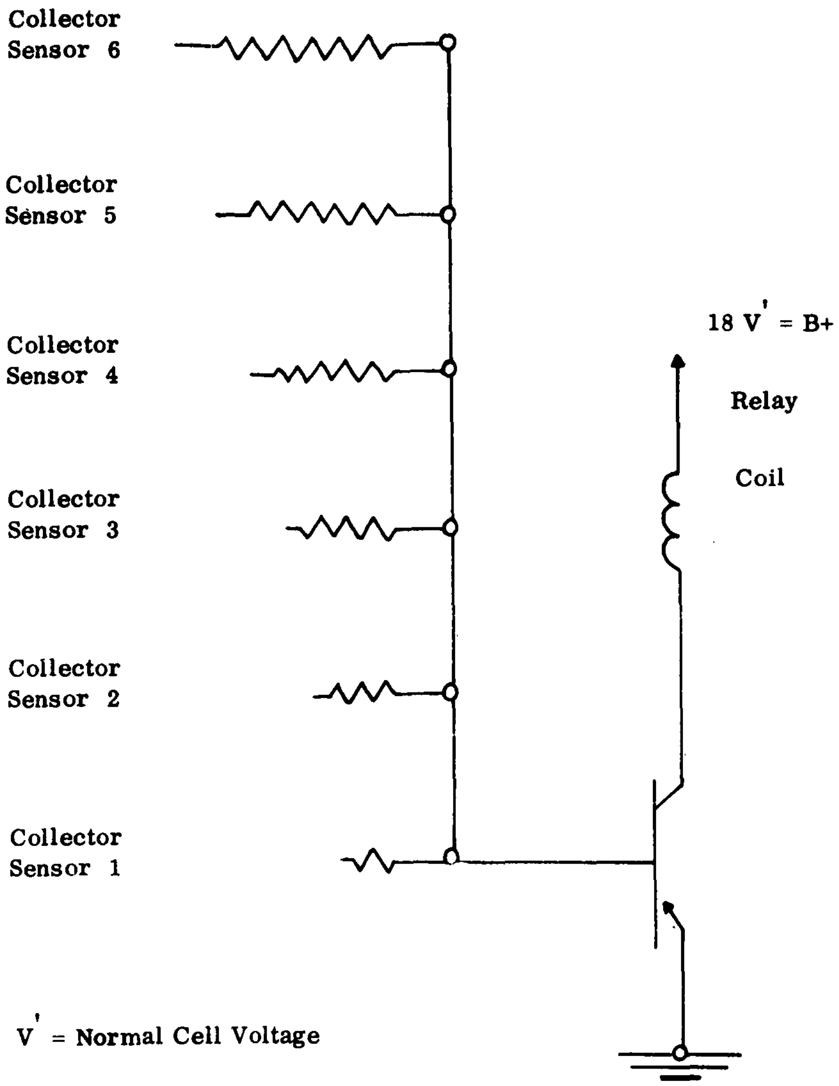


Figure 2-11. "Or Gate" Input from Bottom Six FSSC Voltage Sensors

2.3 RELIABILITY ANALYSIS

The reliability estimate for the fuel cell control subsystem components is 0.9913 for the FCC and 0.9970 for the FSSC for the 7-day mission. The reliability analysis was based on the fact that the parts selected are similar in quality and design to those used in MSD's ADVENT, OAO and NIMBUS programs and that all electronic parts obey the exponential failure law and are statistically independent. The estimated reliability of the subsystem components is given by the general equation: $R = e^{-(\lambda_1 t + \lambda_2)}$ where failure rate, λ_1, is applicable for time dependent parts, and failure rate, λ_2, is applicable for cyclic parts. The parts usage and application data sheets, calculations, and summary tables of assigned failure rates for the corresponding parts used for the reliability estimate are included in Appendix 2B.

Two design reviews of the FCC were conducted, one emphasizing the circuit design and the other emphasizing the product design. The design review attendees included engineering personnel from other programs in the Re-entry Vehicle Department, the Advanced Space Vehicles Department, as well as the Spacecraft Department. Though several review action items resulted for follow-up, there was general acceptance of the overall design at the conclusion of both design reviews. Two suggestions for circuit design improvement were a variation in the potentiometer wiring scheme to minimize voltage fluctuations in case of wiper bounce during high vibration levels and decoupling of noise at the silicon-controlled rectifier gate-to-cathode junction of the timing oscillator and purge sequence relay driver circuits. Weight reduction through the use of magnesium-lithium alloy as the chassis material was suggested to minimize the chassis-to-total unit weight ratio. The changes above were considered to be desirable improvements but not mandatory for Phase Ia and were not incorporated immediately since a schedule delay would have been incurred.

2.4 ELECTRONIC PARTS PROCUREMENT/FABRICATION STATUS

Almost all electronic parts ordered have been received from vendors, all necessary parts from MSD electronic stock were acquired and accumulated, and all electronic parts requested from ADVENT termination stock were transferred. Only parts not received were 16 printed circuit boards (4 each of boards C, D, E, and H) and miscellaneous resistors. The above parts procurement was planned to cover only 3 DTV FCC units and 2 FSSC breadboard units. The following breadboard circuits were fabricated in this reporting period:

- Fuel Cell Controller (Non-Flight Parts)

  Purge Voltage Sensor, Figure 2-12
  Purge Sequence Control, Figure 2-13
  $H_2/0_2$ Differential Pressure Purge Override, Figure 2-14
  Temperature Control, Figure 2-15

- Fuel Supply Shutoff Controller (Non-Flight Parts)

  FSSC Undervoltage Sensors and Control, Figure 2-16

Figure 2-17 is the fuel cell control subsystem test setup showing interconnection of all breadboards to a simulated fuel cell module and a simulated flight battery.

Original plans included fabrication of a FCC breadboard with flight parts. However, a decision was made to bypass the flight parts breadboard and install the parts on sample printed circuit boards received from the vendor. The other FCC parts (relays, timer-counter electronic modules, silicon-controlled rectifiers, and connectors) were mounted into a DTV-FCC case, and this unit was designated as the interim DTV-FCC spare unit. It was planned to transfer the flight parts from the sample printed circuit boards to the DTV printed circuit boards after the other two DTV-FCC prime units were assembled.

2.5 FUEL CELL CONTROL ELECTRONICS TEST STATUS

2.5.1 Fuel Cell Control Electronic Parts Testing (Detailed Test Procedures in Appendix 2C)

All parts were checked visually for structural defects upon receipt and prior to insertion into the printed circuit boards. In addition, tests peculiar to each part were performed at an ambient temperature of 25°C by standard methods. The tests were as follows:

- Resistors

  Resistors for use in the DTV units were only checked for a nominal resistance value.

- Potentiometers

  All potentiometers were checked for a nominal resistance value, and for "opens" along the complete wiper traverse.

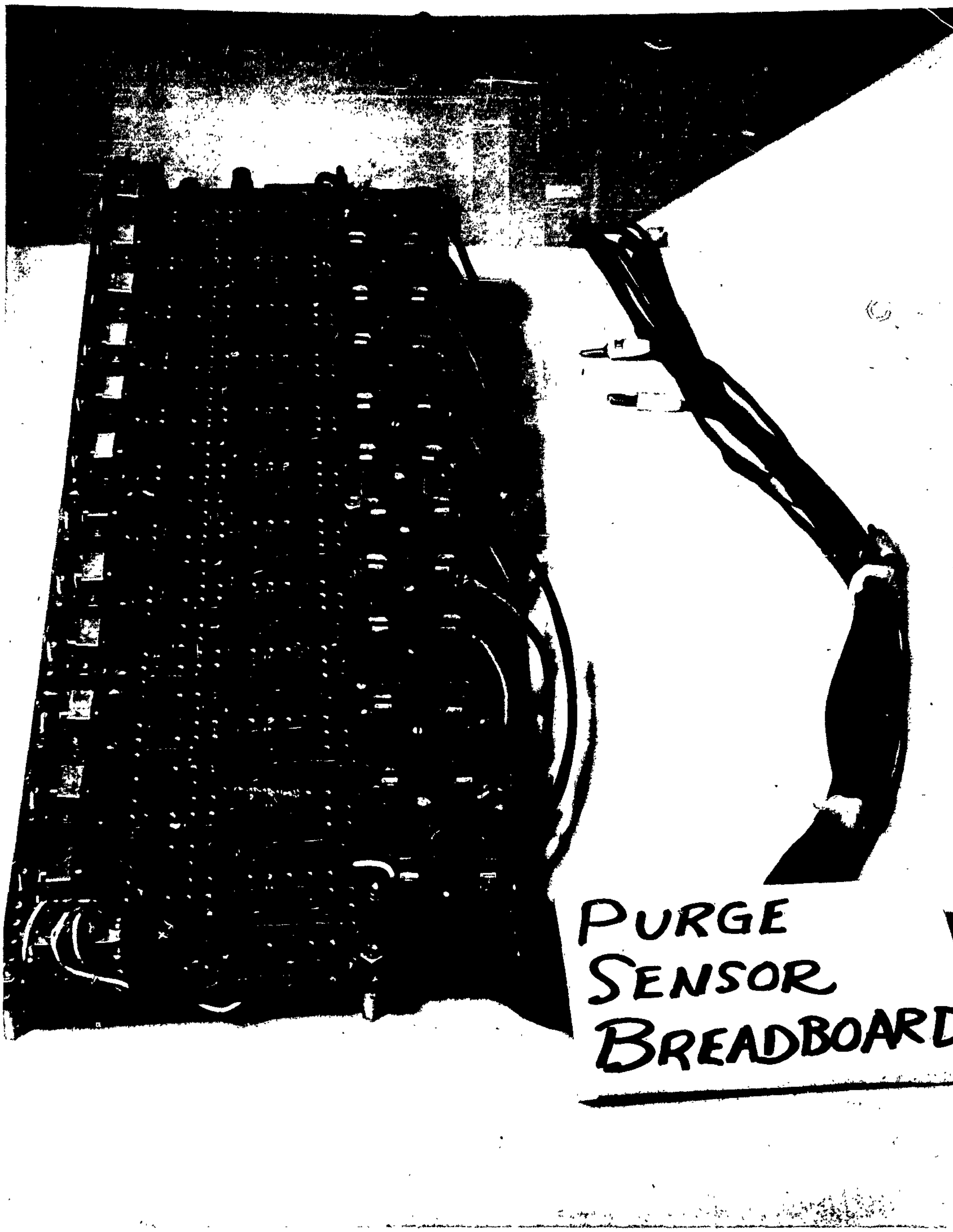


Figure 2-12. Purge Voltage Sensor Breadboard

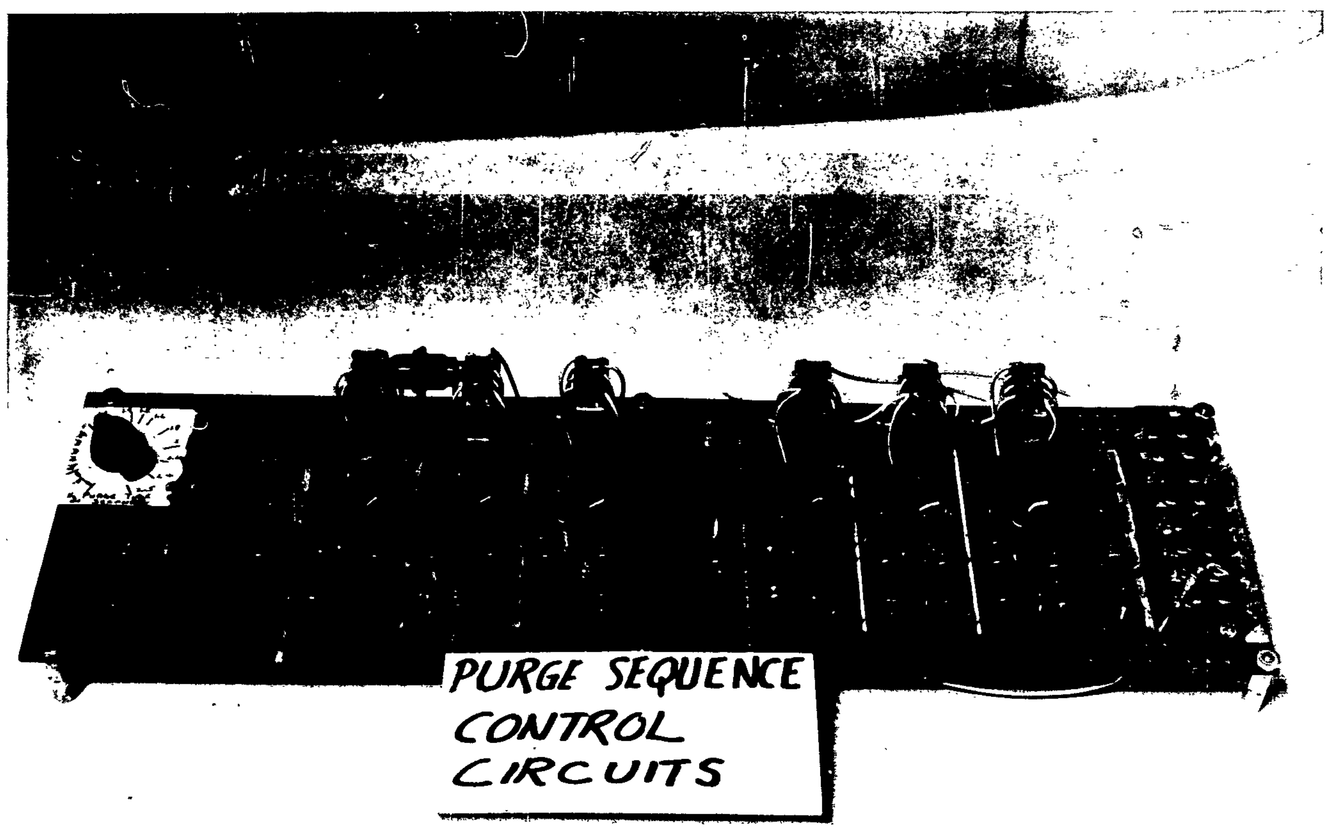


Figure 2-13. Purge Sequence Control Circuits

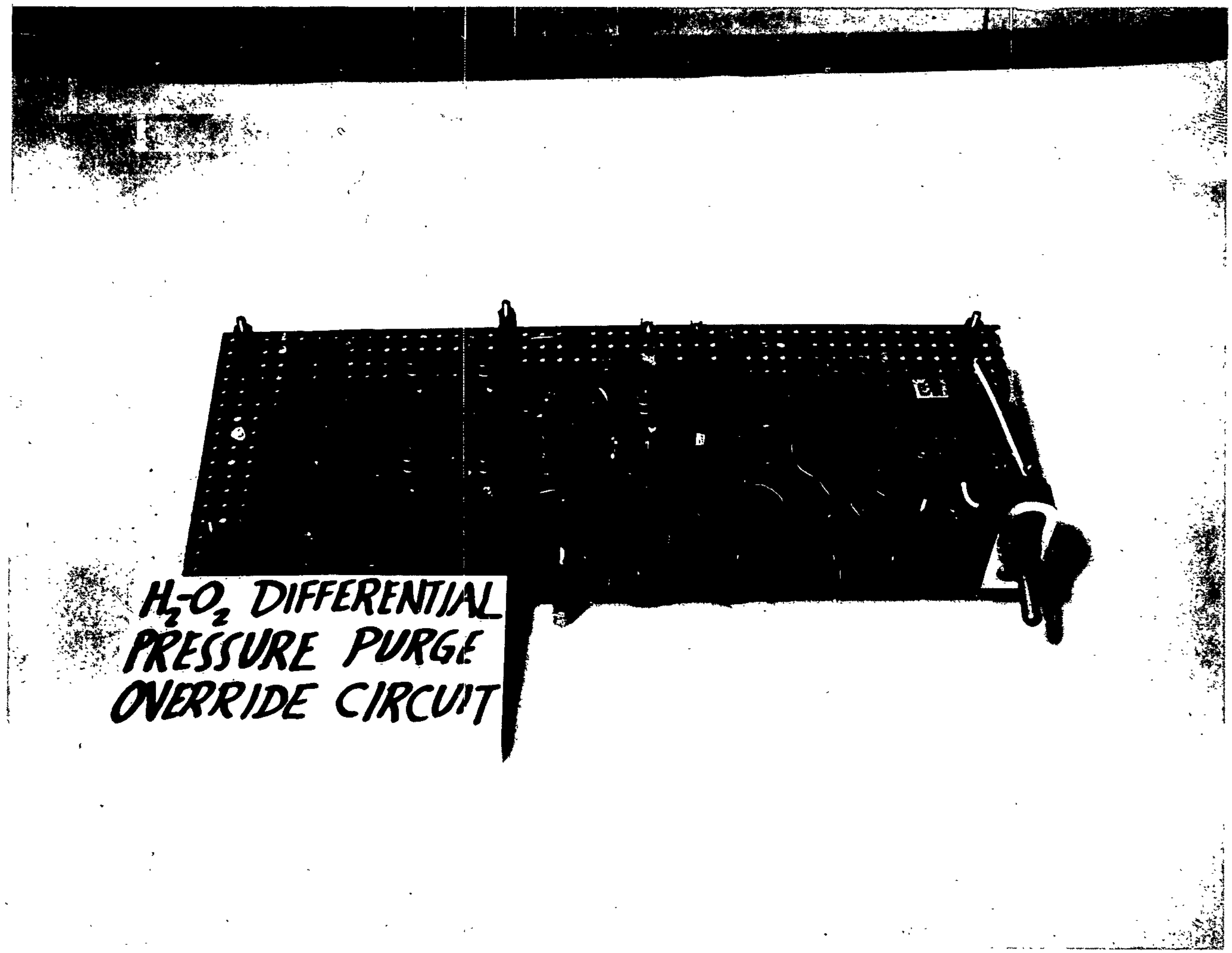


Figure 2-14. H_2-O_2 Differential Pressure Purge Override Circuit

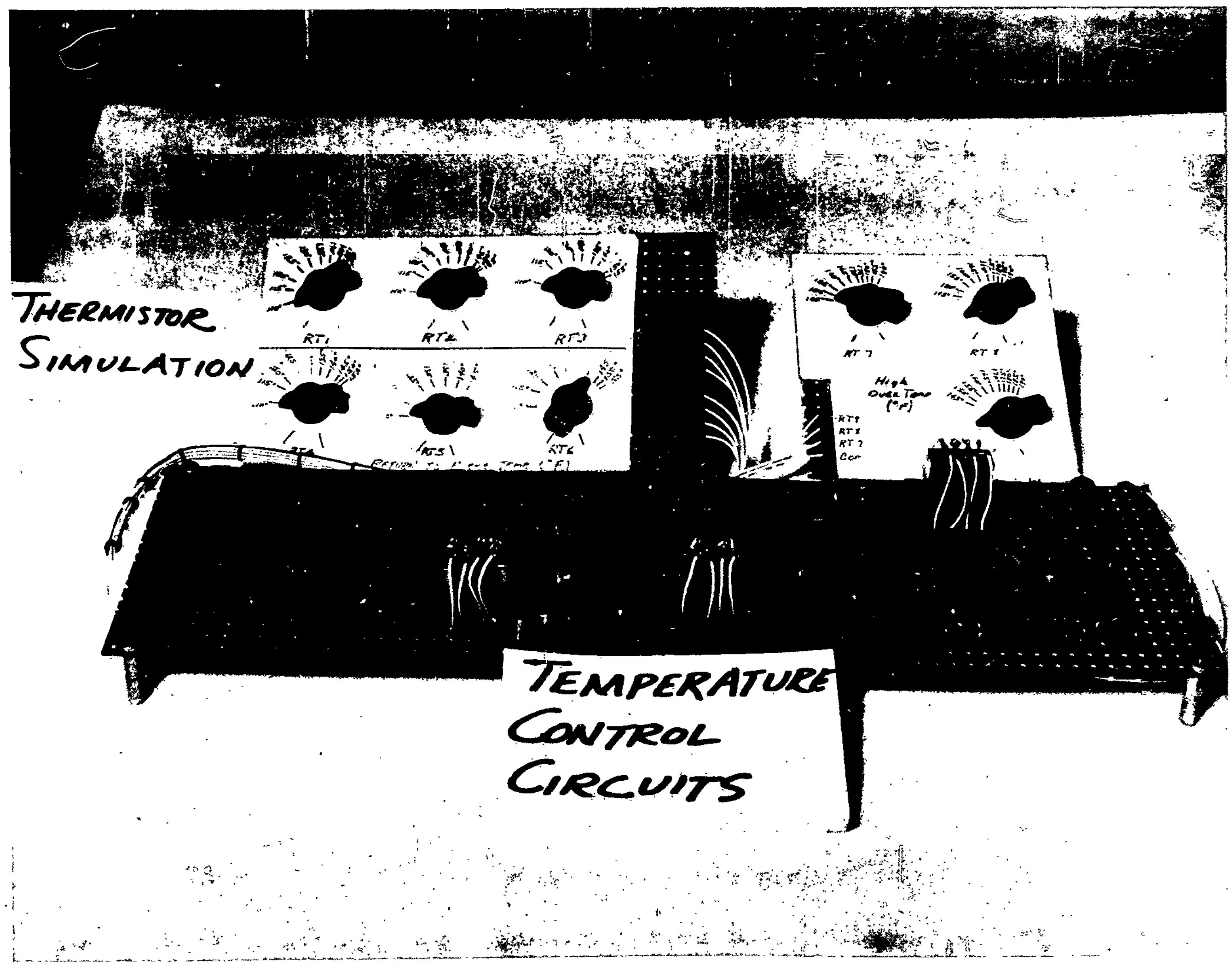


Figure 2-15. Temperature Control Circuits

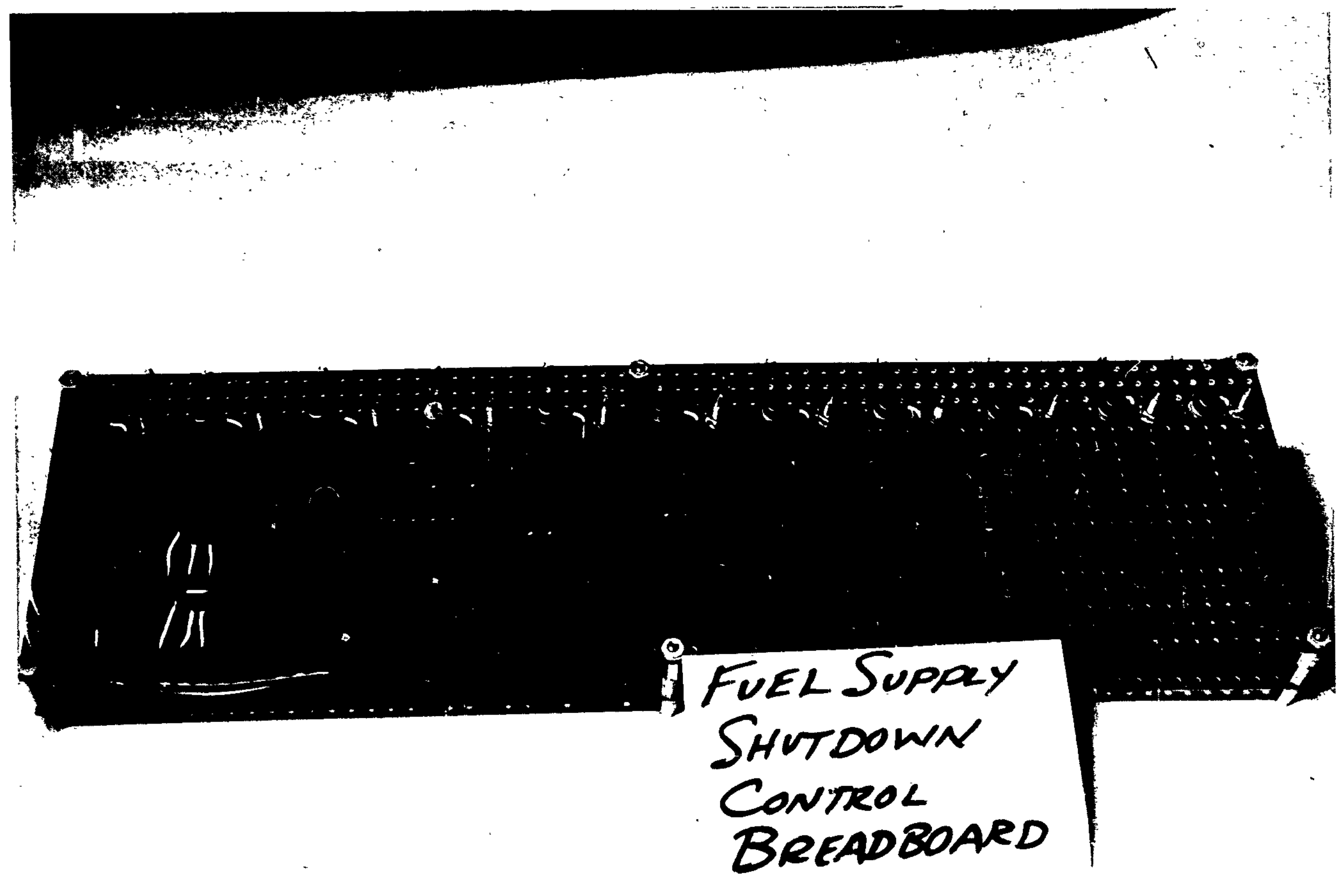


Figure 2-16. Fuel Supply Shutdown Control Breadboard

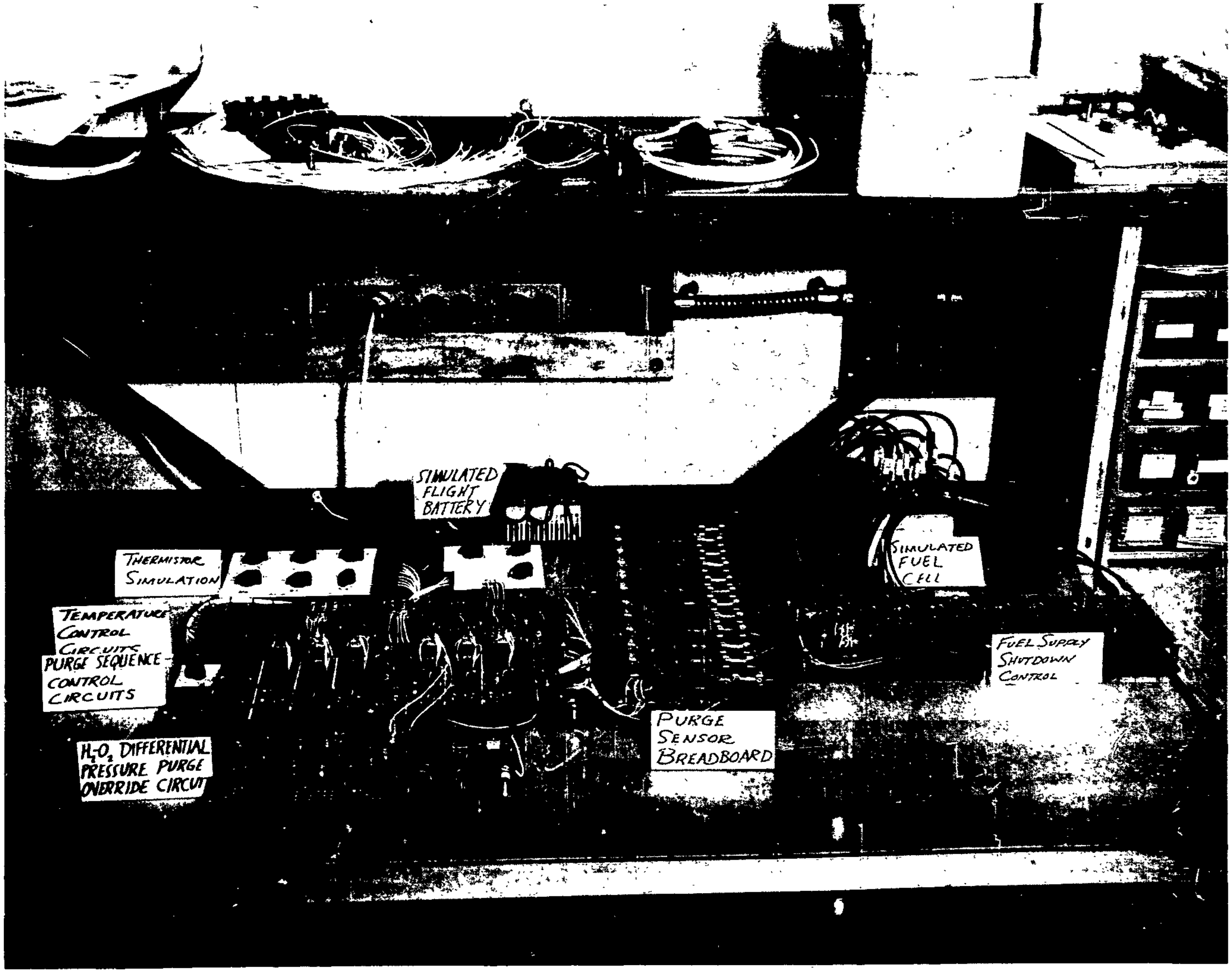


Figure 2-17. Fuel Cell Control Subsystem Test Set-Up

- Capacitors

  Capacitors for use in the DTV units were only checked for a nominal capacitance value.

- Relays

  All magnetic relays were checked for coil resistance, insulation and contact resistance, pull-in and drop-out voltage, operate and release time, and contact bounce.

  All latching relays were checked for coil resistance, insulation resistance, contact resistance, and pull-in voltage.

- Diodes

  Diodes for use in the DTV units were only checked for static forward and reverse resistance.

- Zener Diodes

  All zener diodes were checked for their zener voltage under four conditions of biasing peculiar to their circuit application.

- UJT's

  All unijunction transistors were checked for intrinsic standoff ratio, interbase resistance, emitter leakage current, and base one peak pulse voltage at standard test conditions.

- SCR's

  All silicon controlled rectifiers were checked for forward breakover voltage, holding current, and the 36-volt anode to cathode voltage gate firing characteristic.

- Transistors

  All transistors were checked for their input characteristics, their collector characteristics, Iceo and Ices under the limiting conditions peculiar to their circuit application.

2.5.2 Fuel Cell Controller Testing (Detailed Test Procedures and Results in Appendix 2C)

- Voltage Sensors

Both complementary voltage sensing circuits were checked for excessive semi-conductor and relay power dissipation, and case temperature at ambient temperatures of -17°C, +18°C, and +65°C, and at input voltages of 1.3, 1.5, 1.8, and 2.1 volts. It was found that the maximum power dissipated at any one set of case temperature-input voltage conditions for the transistors was less than .1 of the maximum rating at 75°C case temperature, and that the maximum power dissipated at maximum ambient temperature for the zener diodes was less than .3 of the maximum rating at 75°C ambient temperature. For the relays it was found that the maximum case temperature was .76 of the maximum rating.

In addition, one of the complementary circuits was checked for change in input voltage required to initiate a purge at ambient temperatures of 25°C, 50°C, and 75°C, and at voltage sensor B+ of 10, 11, 12, 13, and 14 volts. It was found that the maximum change in input voltage required to initiate a purge with respect to temperature, with B+ constant, was .7mv/$^{\circ}$C and that the maximum change in input voltage required to initiate a purge with respect to B+, with temperature constant, was -66.5mv/v.

- 20-Volt Series Regulator

The 20-volt series regulator was checked, with maximum load on the output, for excessive semi-conductor power dissipation and case temperatures at ambient temperatures of 25°C, 50°C, and 75°C, and at input voltages of 20, 28, and 33 volts. It was found that the maximum power dissipated at any one set of case temperature input voltage conditions for the transistors was less than .2 of the maximum rating at 75°C case temperature, and that the maximum power dissipated at any ambient temperature for the zener diode was less than .02 of the maximum rating at 75°C ambient temperature.

In addition, the maximum change in output voltage from no load to full load was 1.9 volts and occurred at minimum input voltage.

- <u>Total Module Undervoltage Sensor</u>

  The HOPE termination preceded the period set aside for the detailed thermal testing of the total module undervoltage sensor. Future effort should be directed towards checking for excessive semi-conductor and relay power dissipation and case temperatures at ambient temperatures of 25 $^{\circ}$C, 50 $^{\circ}$C, 75 $^{\circ}$C, and at various input voltages. Also to be checked should be the change in input voltage indicating a total module undervoltage with respect to temperature and B+ at ambient temperatures of 25 $^{\circ}$C, 50 $^{\circ}$C, and 75 $^{\circ}$C, and at values of B+ of 33 volts to 20 volts.

- <u>Temperature Sensor</u>

  The HOPE termination preceded the periods set aside for the detailed thermal testing of the temperature sensor. Due to the fact that this is a "single-shot" type sub-circuit, future effort should be directed towards determining the change in input voltage (analog of fuel cell temperature, indicating an over-temperature or return-to-normal temperature) to perform the switching function with respect to temperature and B+ at ambient temperatures of 25 $^{\circ}$C, 50 $^{\circ}$C, and 75 $^{\circ}$C, and at a B+ of 20 volts $\pm$ 1 volt. False triggering of the SCR switch due to temperature and noise is also an area of planned future investigation.

- <u>Purge Sequencer</u>

  Arcing across relay contacts and inductive "kick" was investigated in the purge sequencer subcircuit. Since micro-amp switching was involved, contact arcing was eliminated. Inductive "kick" was held to a maximum of 5 volts due to the slow characteristic switching speed of the SCR switch.

  The HOPE termination preceded the period set aside for the detailed thermal testing of the purge sequencer. Since this subcircuit operates under pulse conditions, future effort should be directed towards determining the change in the characteristic time delay with respect to temperature and B+ at ambient temperatures of 25 $^{\circ}$C, 50 $^{\circ}$C, and 75 $^{\circ}$C, and at values of B+ of 20 volts to 33 volts. False initiation or completion of the characteristic time delay, due to thermal and noise triggering of the SCR switch, is also an area of planned investigation.

. <u>Solenoid Valve Switch</u>

The solenoid valve switching sub-circuit was also investigated for arcing across relay contacts and inductive "kick." By the use of a capacitor across the relay contacts low current switching was achieved to minimize contact arcing. By the use of diodes, inductive "kick" was held to a maximum of 3 volts.

. <u>Purge Counter-Timer Testing</u>

The purge counter-timer test schematics, test procedures, and test results are presented in Appendix 2C. Tests of the purge counter-timer system and of the individual electronic modules making up the system were conducted at temperatures of 25^{o}C, -55^{o}C, and 75^{o}C. Additionally, each individual module was tested with input voltages of 18 v, 20v, 22v, or 10v, 11v, or 12v, depending on the input requirement of the module tested. All tests were conducted by the vendor and results were within specification limits. Preliminary testing of these modules under nominal and ambient conditions of the DTV-FCC unit indicates compatibility of the five electronic module counter-timer sub-circuits with the other FCC sub-circuits.

2.5.3 <u>Fuel Supply Shutoff Controller</u>

Only developmental testing at room ambient conditions was accomplished. Results of these tests indicate that a practical circuit was developed which could replace the present FCC purge voltage sensor when fully evaluated by further testing.

2.5.4 <u>Fuel Cell Control Subsystem</u>

The non-flight parts breadboards were interconnected as shown in Figure 2-17 and subsystem performance (without the timer-counter modules) was successfully demonstrated. The breadboard subsystem consisted of:

. Dry cell battery packs, simulating the fuel cell module and the flight battery.

. Purge voltage sensing and control breadboard.

. Purge sequencing and control breadboard.

- Temperature control breadboard with potentiometers simulating the fuel cell thermistor temperature sensors.
- H_2/O_2 differential pressure purge override breadboard.
- Lights simulating fuel supply, purge solenoids, and vehicle load.

Each FCC purge voltage sensor was set to initiate a purge when the fuel cell stack voltages dropped to 1.5 volts for a 2-cell stack and 2.25 volts for a 3-cell stack. In the test, two dry cells provided from 2.8 to 3 volts so that a purge was initiated by moving a voltage sensor lead to sense only one dry cell. Purge sequencing times were observed and by measuring the light on/off times were determined to be adjustable within the specification limits. Temperature control was exercised by changing the resistance of the potentiometers, thereby simulating the thermistor resistance change as a function of temperature in the fuel cell. Overtemperature load cutoff and return-to-normal temperature load reclose was demonstrated in this manner. Although the 180°F fuel supply shutoff requirement had been deleted, the breadboard circuit was demonstrated since the circuit had been fabricated and checked-out before dropping the requirement. Differential pressure purge override was demonstrated by simulating the H_2 and O_2 pressure transducers with potentiometers which were set to simulate an excessive differential pressure on either side. Fuel supply shutoff was demonstrated in a manner similar to purge initiation.

2.5.5 DTV-FCC

Extensive testing of the DTV-FCC unit was not conducted before termination of the effort. The unit had just been assembled and only preliminary in-process assembly tests were conducted.

2.6 FUEL CELL CONTROL ELECTRONICS PRODUCT DESIGN STATUS

Product design of the DTV-FCC was finalized and a preliminary design of the FSSC was made during this reporting period. Figures 2-18, 2-19 and 2-20 are photographs of a completed DTV-FCC. Details, sketches, and material lists of the DTV-FCC chassis and printed circuit boards are in Appendix 2D. Figure 2-21 is a layout drawing of the DTV-FCC. Photographs of the printed circuit boards and FCC electronic parts are shown in Figures 2-22 and 2-23 respectively.

The finalized packaging concept of the DTV-FCC was slightly modified from the original concept. The "master" board was not used and was replaced by conventional wiring to interconnect all the plug-in printed circuit boards. Also the "wrap-around" rectangular box construction with channel-type stiffeners was

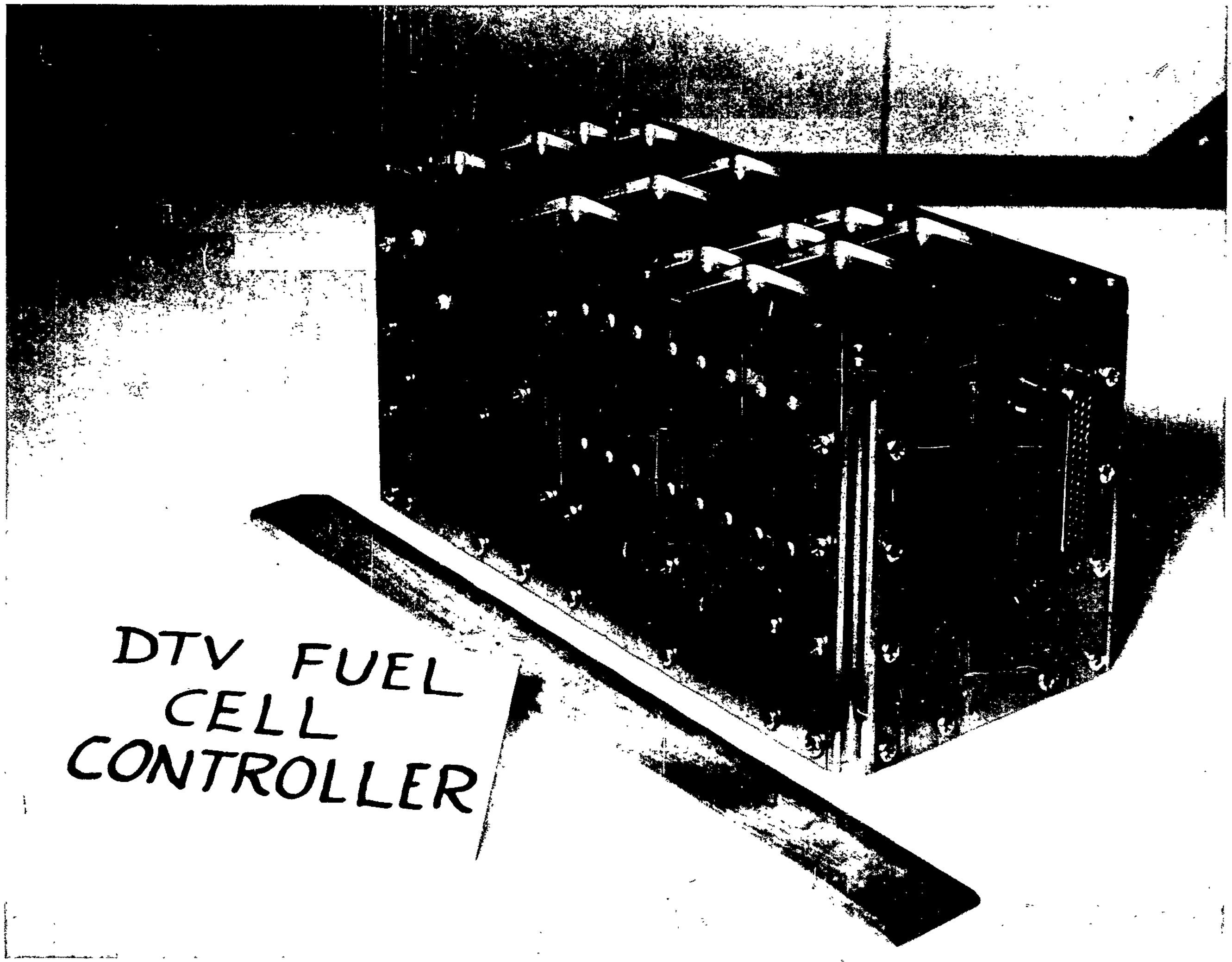


Figure 2-18. DTV Fuel Cell Controller

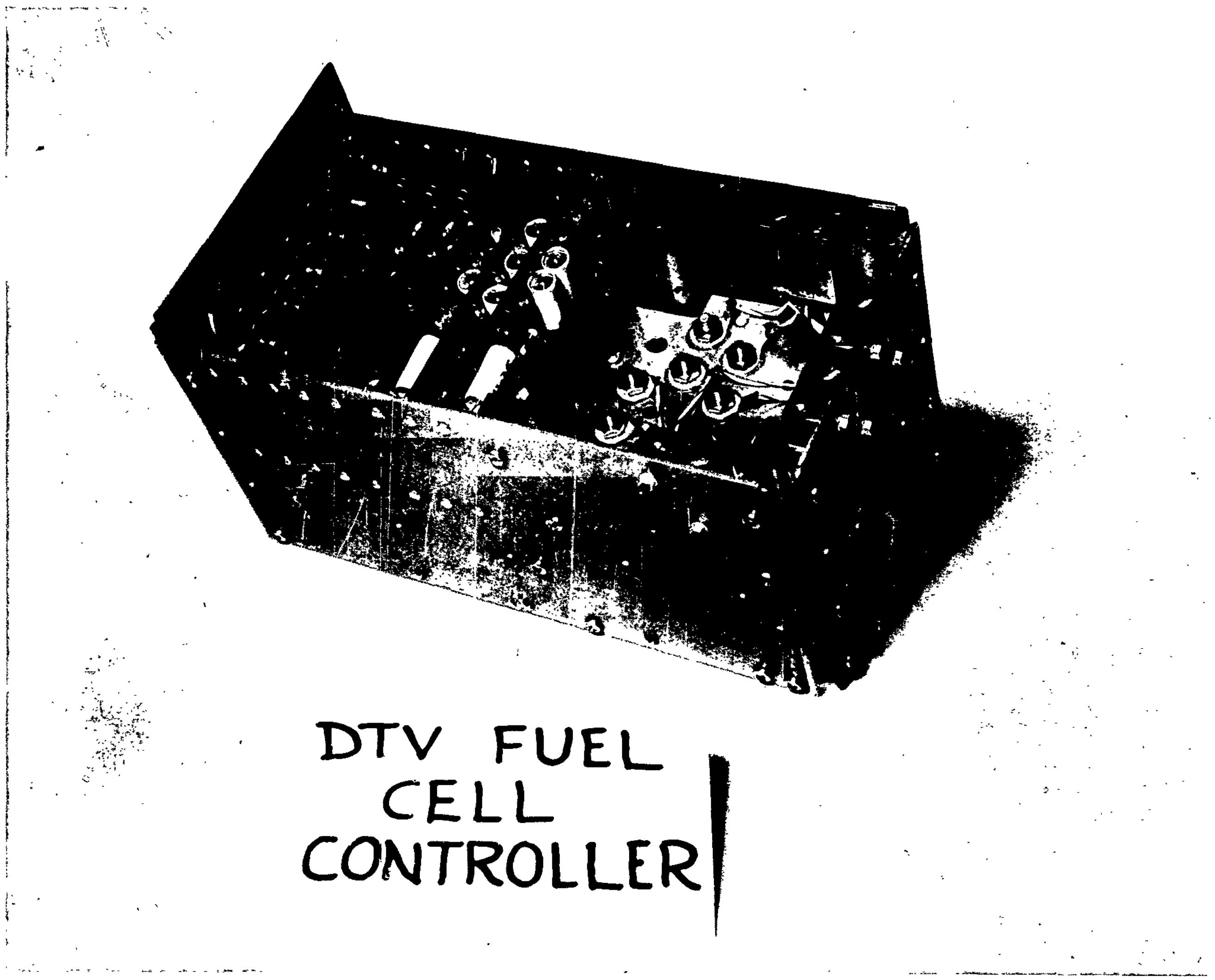


Figure 2-19. DTV Fuel Cell Controller

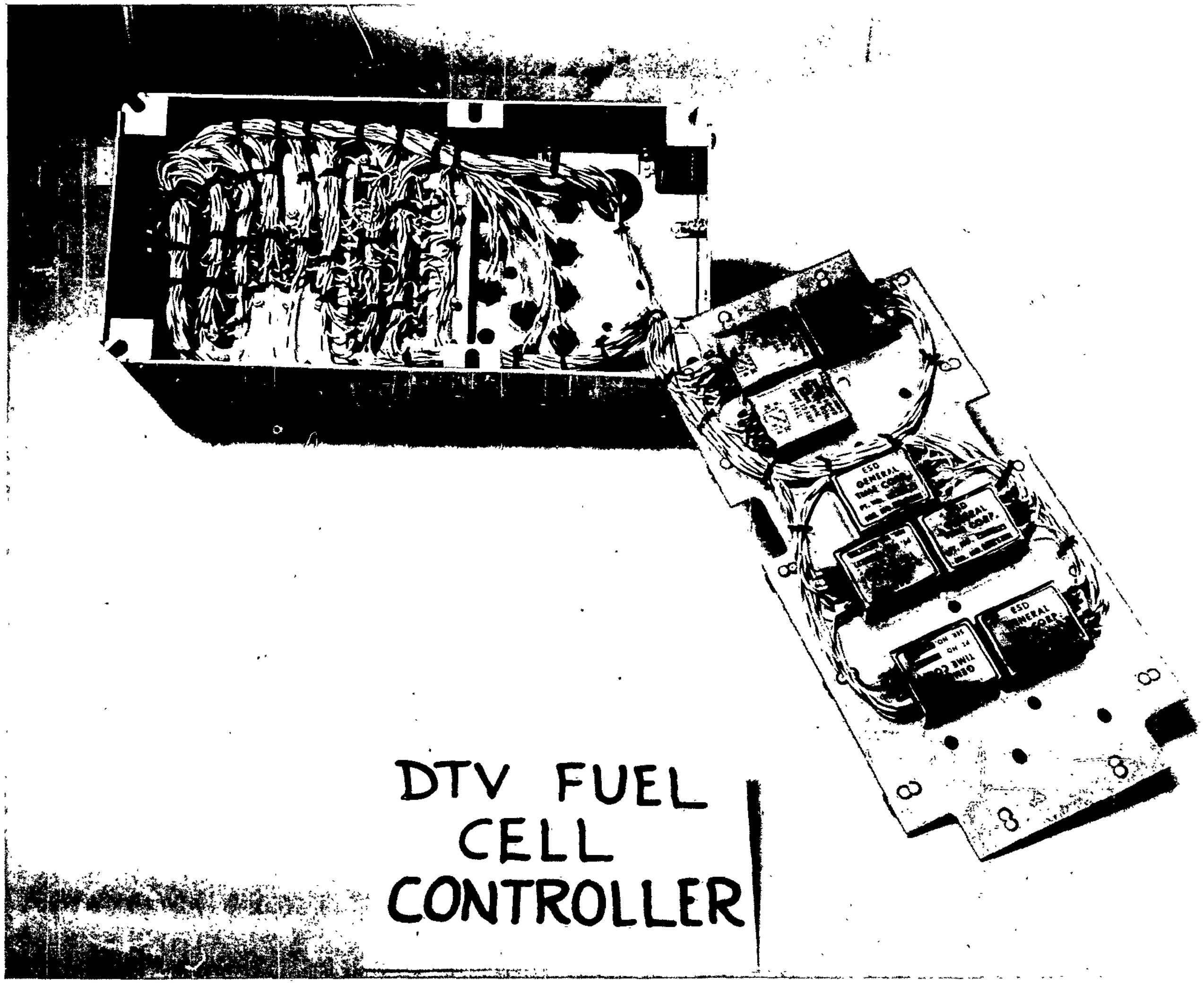
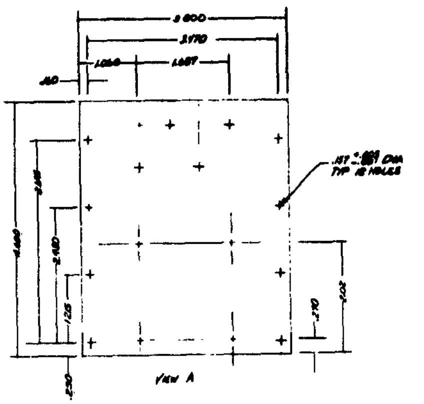
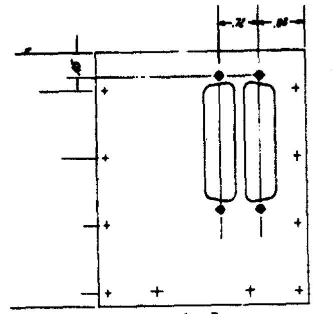


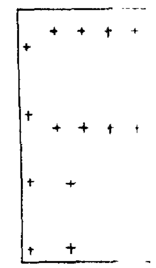
Figure 2-20. DTV Fuel Cell Controller

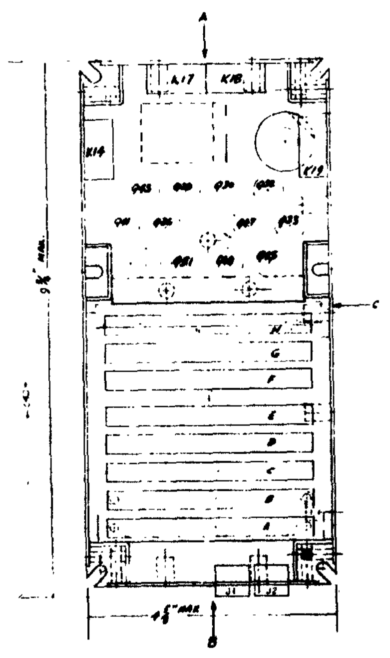


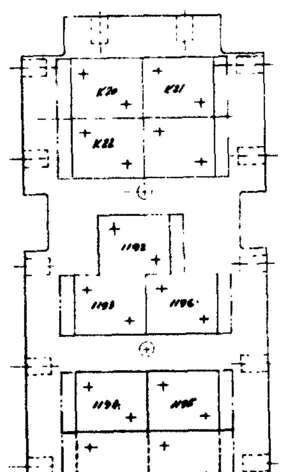
VIEW A



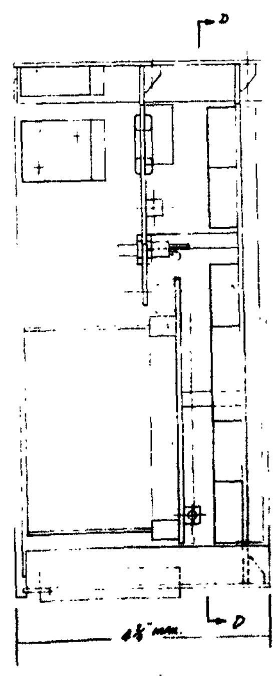
VIEW B







VIEW D-D



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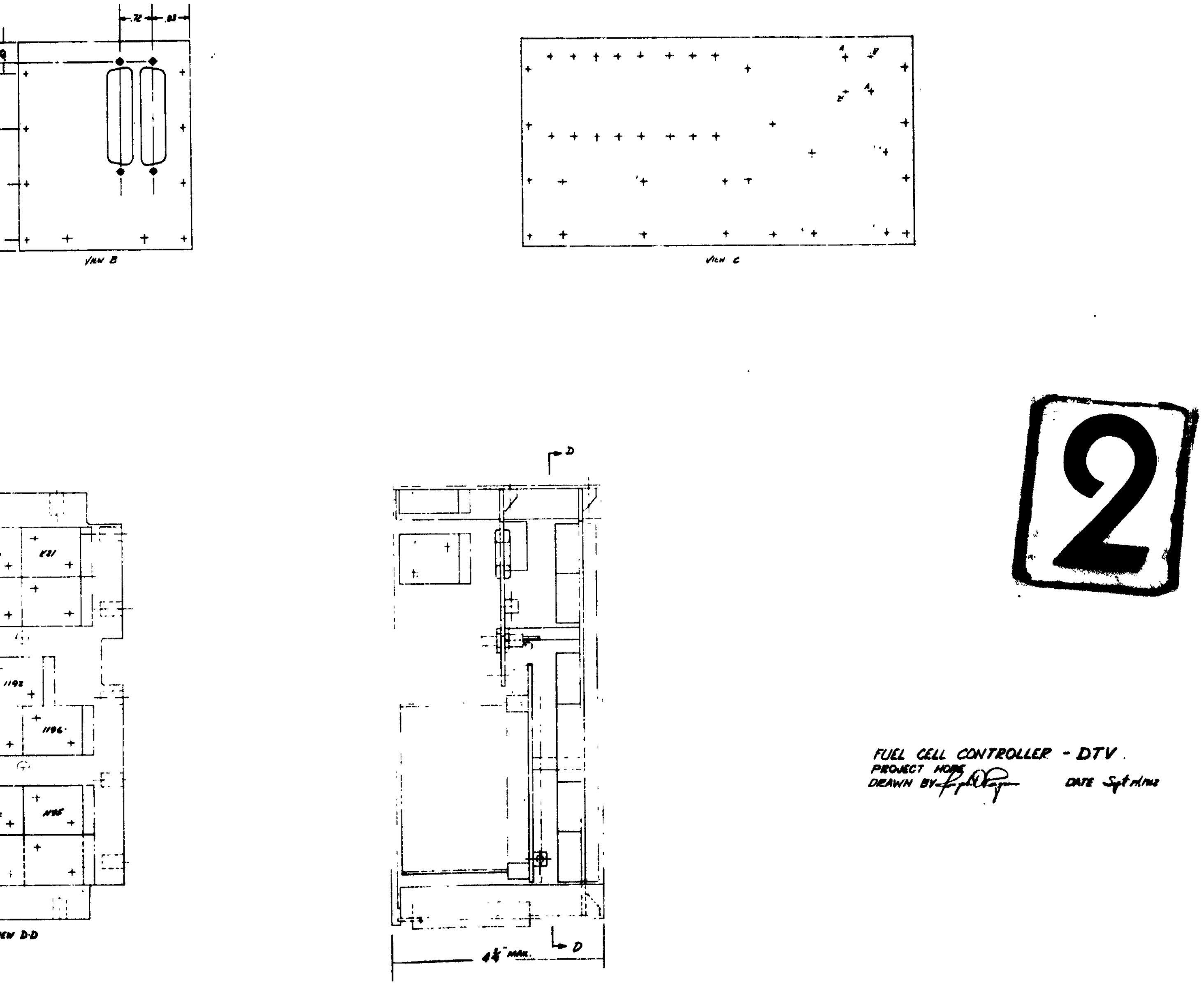


Figure 2-21. Fuel Cell Controller - DTV

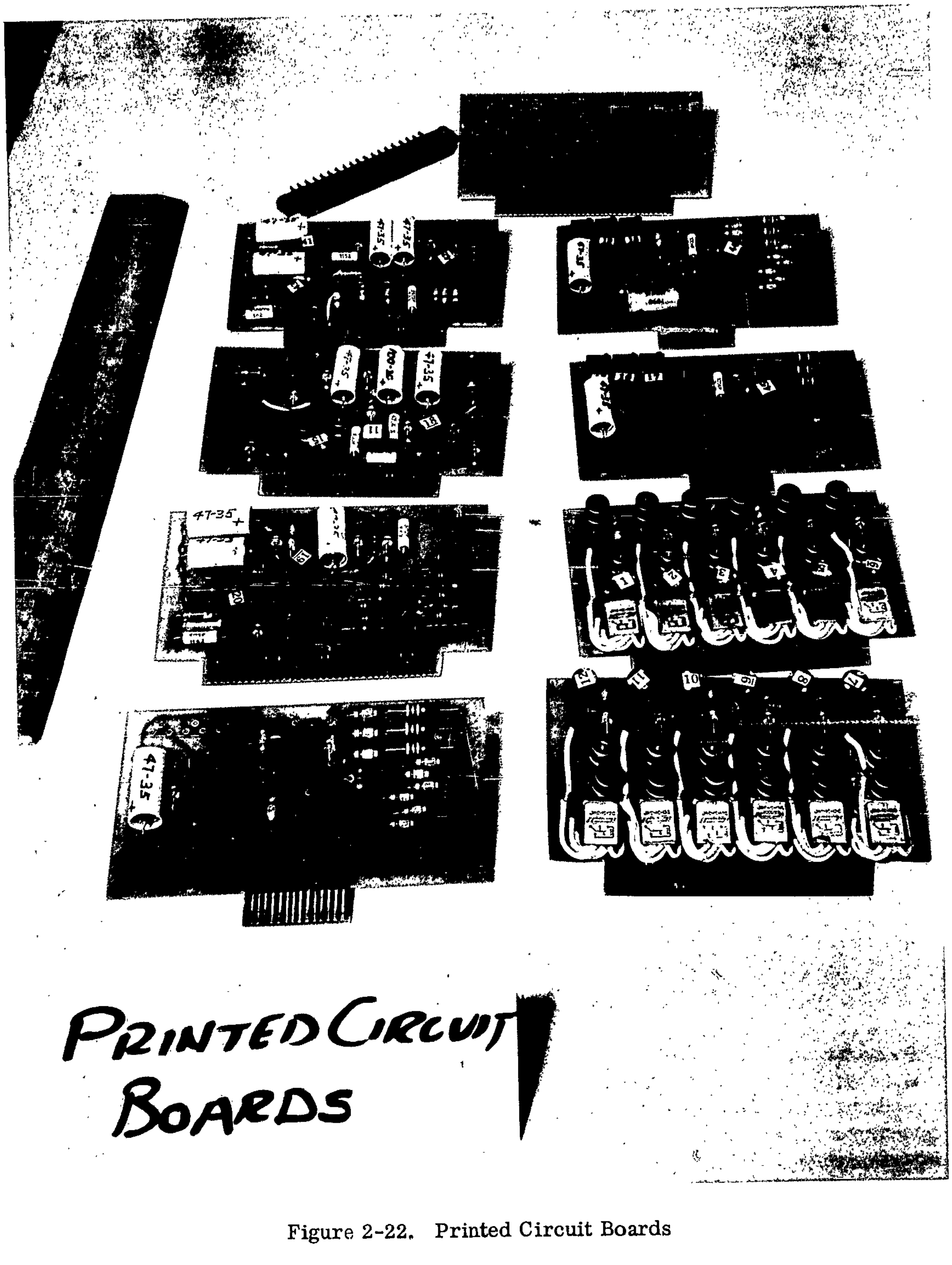


Figure 2-22. Printed Circuit Boards

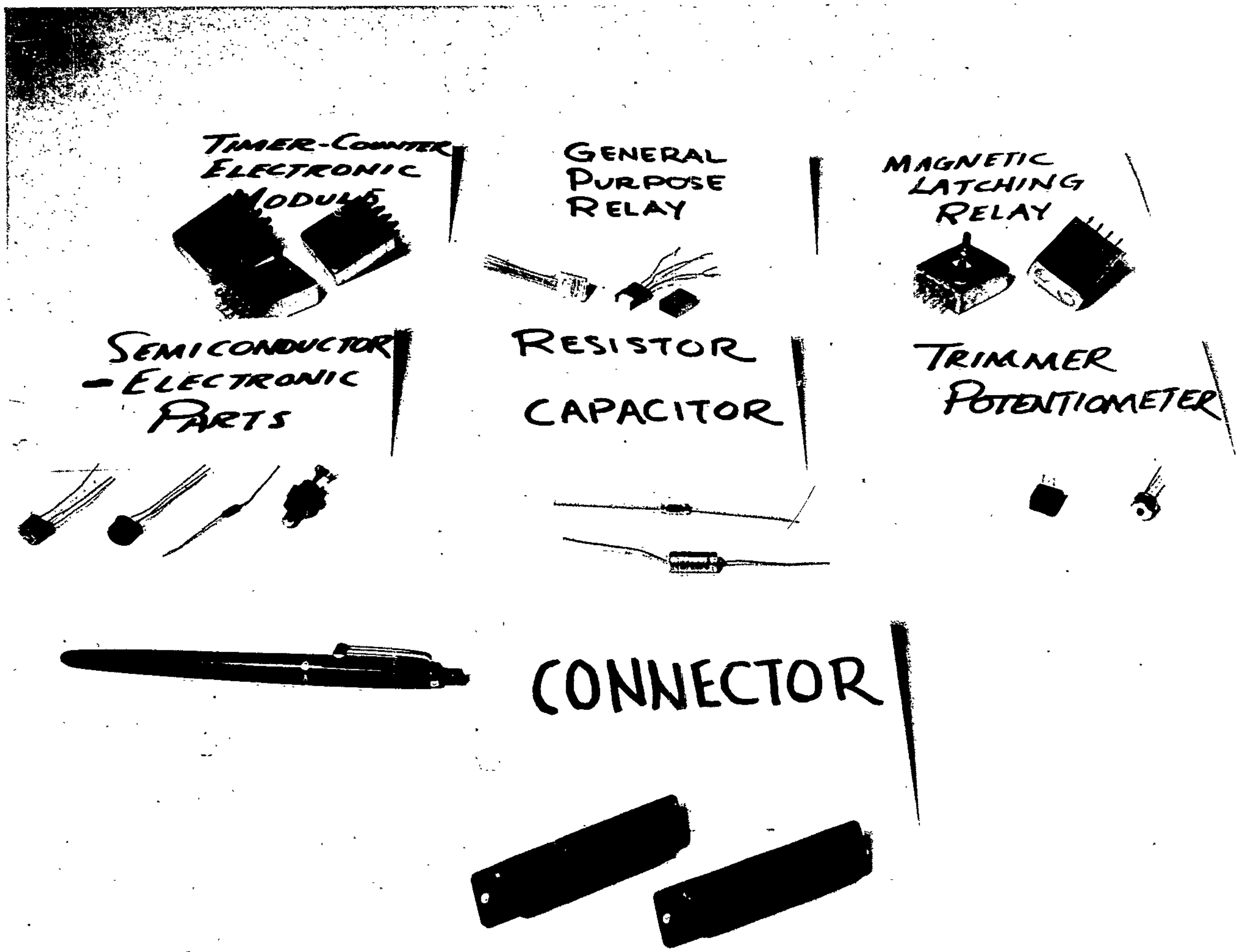


Figure 2-23. FCC Electronic Parts

dropped in favor of flat plates for mounting, and case sides bolted to machined corner and intermediate support posts with helicoil inserts, mainly to meet the DTV schedule and cost limits. Refined construction, utilizing extruded parts, wrap-arounds, channels, etc., was deferred for later design improvement and optimization.

Weight breakdown of the nominally 4-5/8" x 9-3/4" x 4-3/4" DTV-FCC is shown below:

Printed circuit boards with electronic parts......................	1.0 lbs.
SCR's, latching relays, electronic modules, connectors, wiring ...	2.0 lbs.
Case plates, posts, cover and fasteners.........................	3.5 lbs.
Total	6.5 lbs.

A calculation of the printed circuit board deflection using the restrained beam equation with the beam uniformly loaded indicated that heavier plate material and stiffer post supports would be necessary to withstand the high vibration load expected in the longitudinal direction.

The FCC vehicle mock-up installation is shown in Figure 5-19. The magnitude of vibration stress expected is in the longitudinal direction and is 32.5 g's or higher between 100-300 cps for the mounting location selected.

For purposes of thermal control a high emissivity coating was applied to the chassis. The coating selected was VitaVar No. 15966 formulation PV100. For protection against humidity, vibration, handling, etc., a conformal coating which would not char or disfigure, was selected to facilitate quick modifications and repair by direct soldering. The coating selected was Uralane 241/973.

A preliminary design sketch of the FSSC is shown in Figure 2-24. Similar construction as that of the DTV-FCC was assumed which resulted in a 3" x 4.5" x 5" unit weighing an estimated two pounds. The FSSC unit was planned for installation in the electrical compartment adjacent to the flight battery. The two FCC's would then flank the battery and FSSC on the same bulkhead.

2.7 DTV FUEL CELL ELECTRICAL DISCONNECT - DTV HARNESS

During ground testing two 36-pole, single throw, normally closed relays are required for disconnecting the electrical load completely (spacecraft loads, FCC and FSSC) from each fuel cell module. The relay selected for this remote control function shown in Figure 2-25, is a T-bar type relay. Nominal pull-in voltage is 24 V. DC, pull-in coil power is 3.5 watts, contact rating is 3 amperes, resistive (make and break), and weight is 5.5 oz. The unit chosen has not been

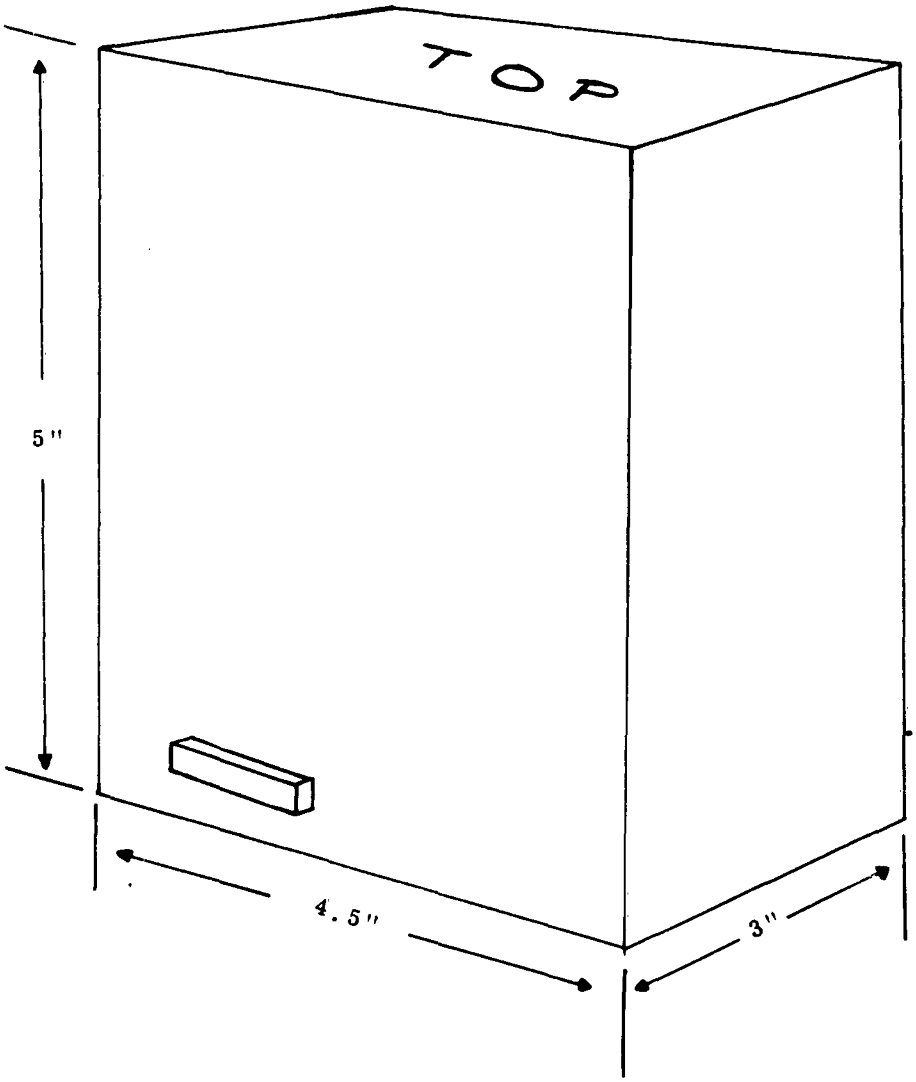


Figure 2-24. H O P E Fuel Supply Shut-Off Controller

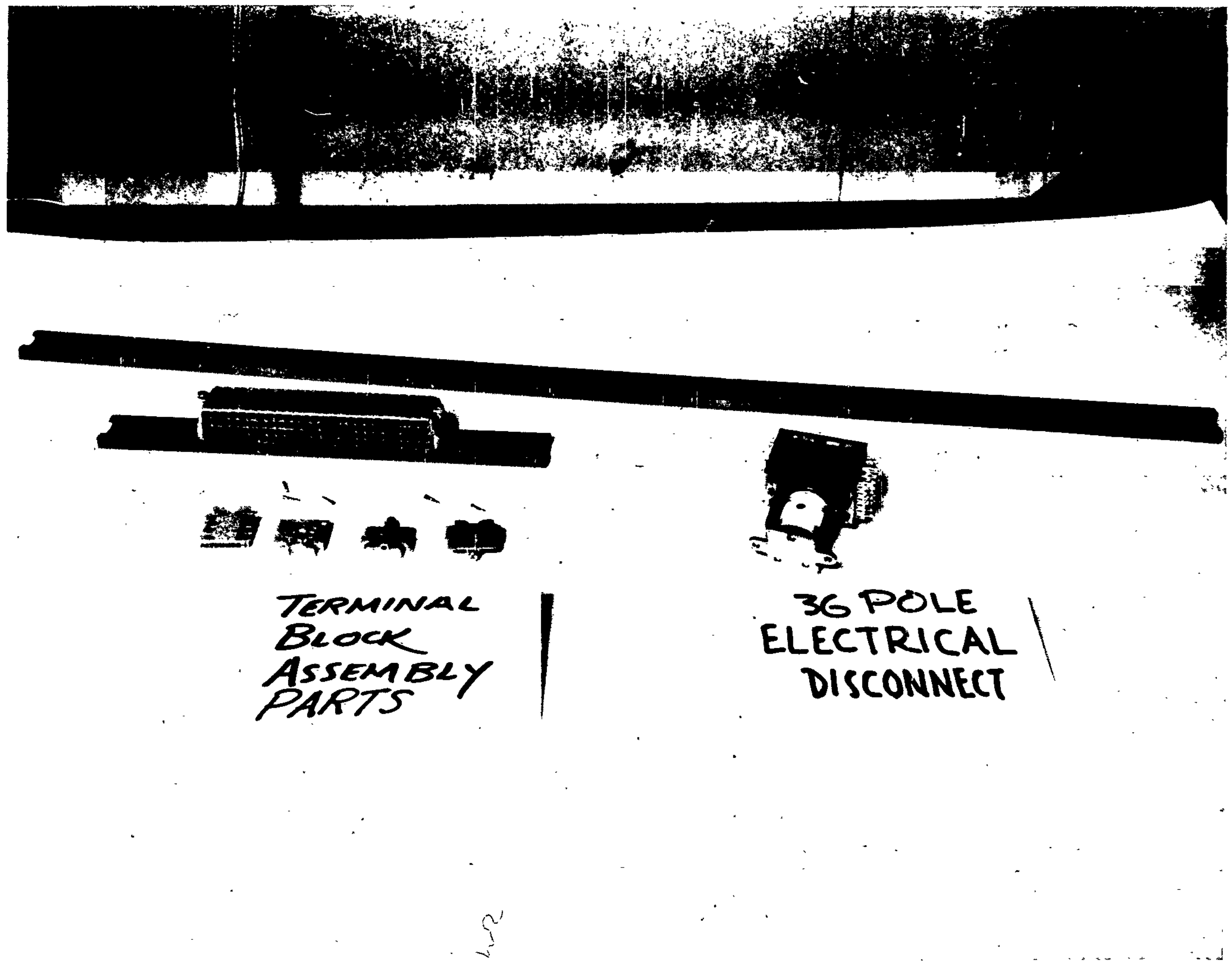


Figure 2-25. T-Bar Type Relay

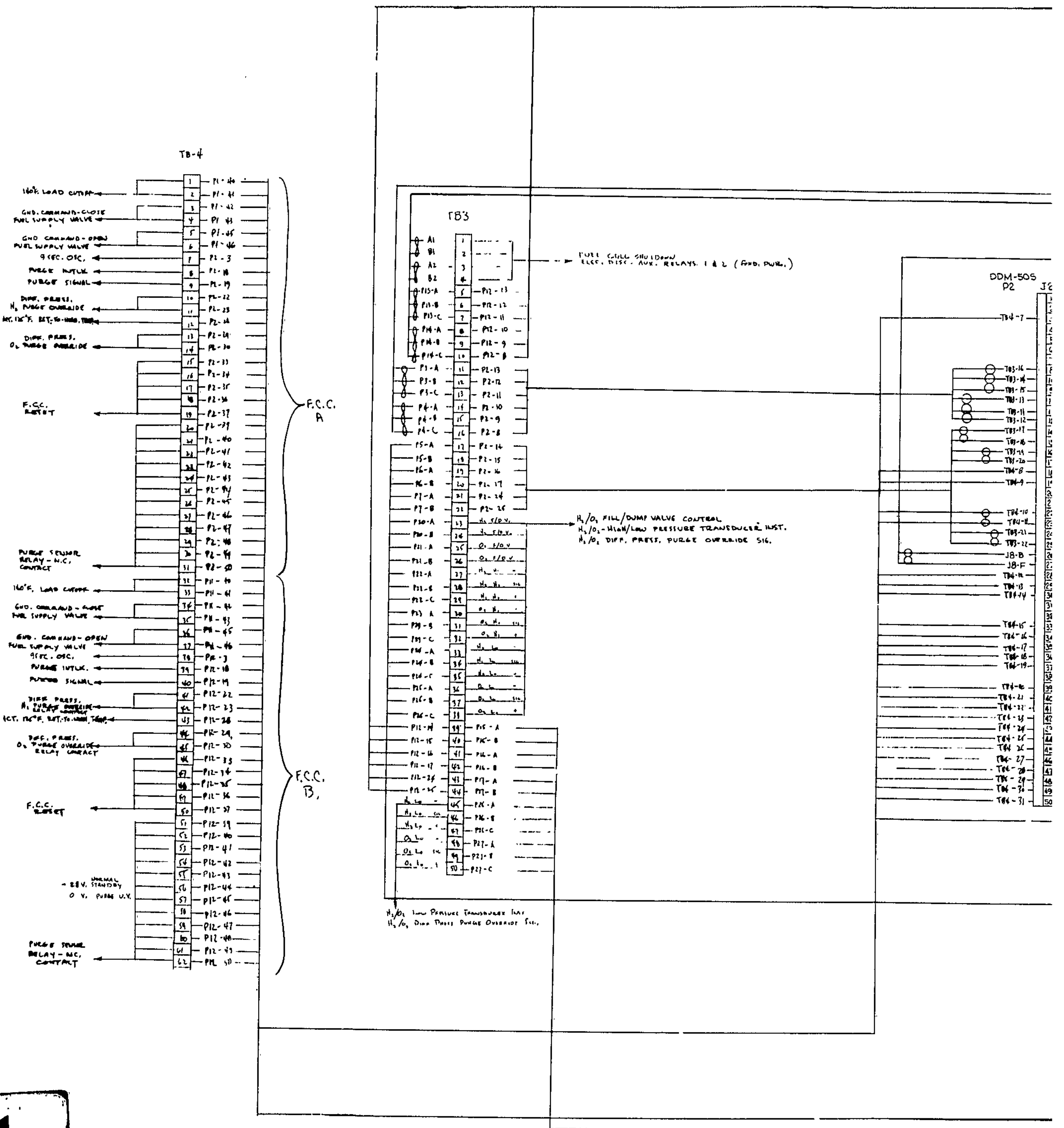
primarily designed for space flight but did appear promising with some modifications to fulfill the flight requirements. No significant design, modification, or testing had been accomplished, however, before curtailment of the effort. Nor had the installation into the DTV vehicle been finalized, although the tentative location selected for the two relay units was in the Experiment Compartment. Power to actuate these relays to disconnect the fuel cells electrically was to be provided by ground power through the umbilical. In flight, the relay coils would be de-energized and the only requirement is that the relays carry the fuel cell current through their normally closed contacts. Other designs were considered, utilizing off-the-shelf items. Six 6-pole, and nine 4-pole, double throw magnetic latching relay combinations, though space-qualified, were evaluated as being too bulky and cumbersome. Another possible design utilized multiple minature Klixon switches operated by a solenoid. The design, however, was for ground support equipment applications and not for space flight.

The DTV internal interconnection wiring diagram is shown in Figure 2-26 Figure 5-19 illustrates a mock-up of the vehicle installation of one of the terminal block assemblies used for interconnection of components within the Electrical Compartment and to other components in adjoining compartments. The assemblies are Burndy Minilok minature, modular terminal blocks with crimp-type snap-in contacts. The parts are shown in Figure 2-25. This type assembly has been approved for space flight and is used extensively in the NIMBUS weather satellite. Four 25-side feed module terminal block assemblies were planned for installation onto one of the Electrical Compartment access doors. Each of the 25-side feed modules can accommodate eight connections in various bussing arrangements, e.g., one electrical point with eight bus connections, two electrical points with four bus connections per electrical point, or four electrical points with two bus connections per electrical point. Also top feed modules are available if desired. The twenty-five modules are held together on a track by two end clamp units. The track is then mounted onto a vehicle support bracket.

2.8 SUMMARY/RECOMMENDATIONS FOR FUTURE EFFORT

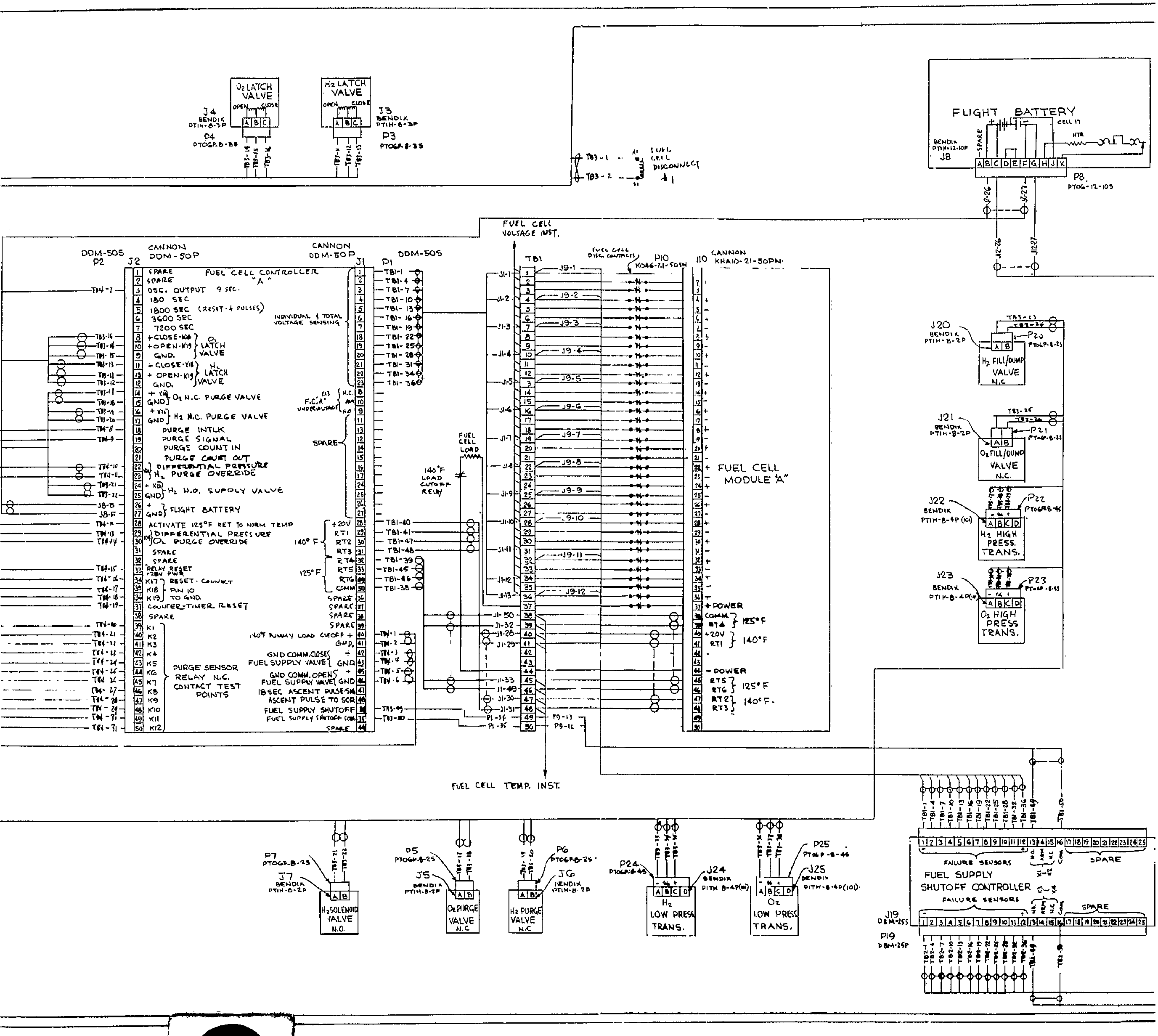
2.8.1 Fuel Cell Controller (FCC)

The present FCC basic design appears adequate overall, although qualification tests were not conducted to verify this. Future efforts should include redesign of printed circuit board "E" to incorporate the present or an equivalent $H_2/0_2$ differential purge override circuit with any modifications as a result of testing the circuit in a temperature chamber. Also, the purge voltage sensor circuit used in the FSSC should be considered. Reliability of the unit can be significantly increased by replacing the potentiometers with selected resistor networks after finalization through the development phase and increasing the tantalum capacitor



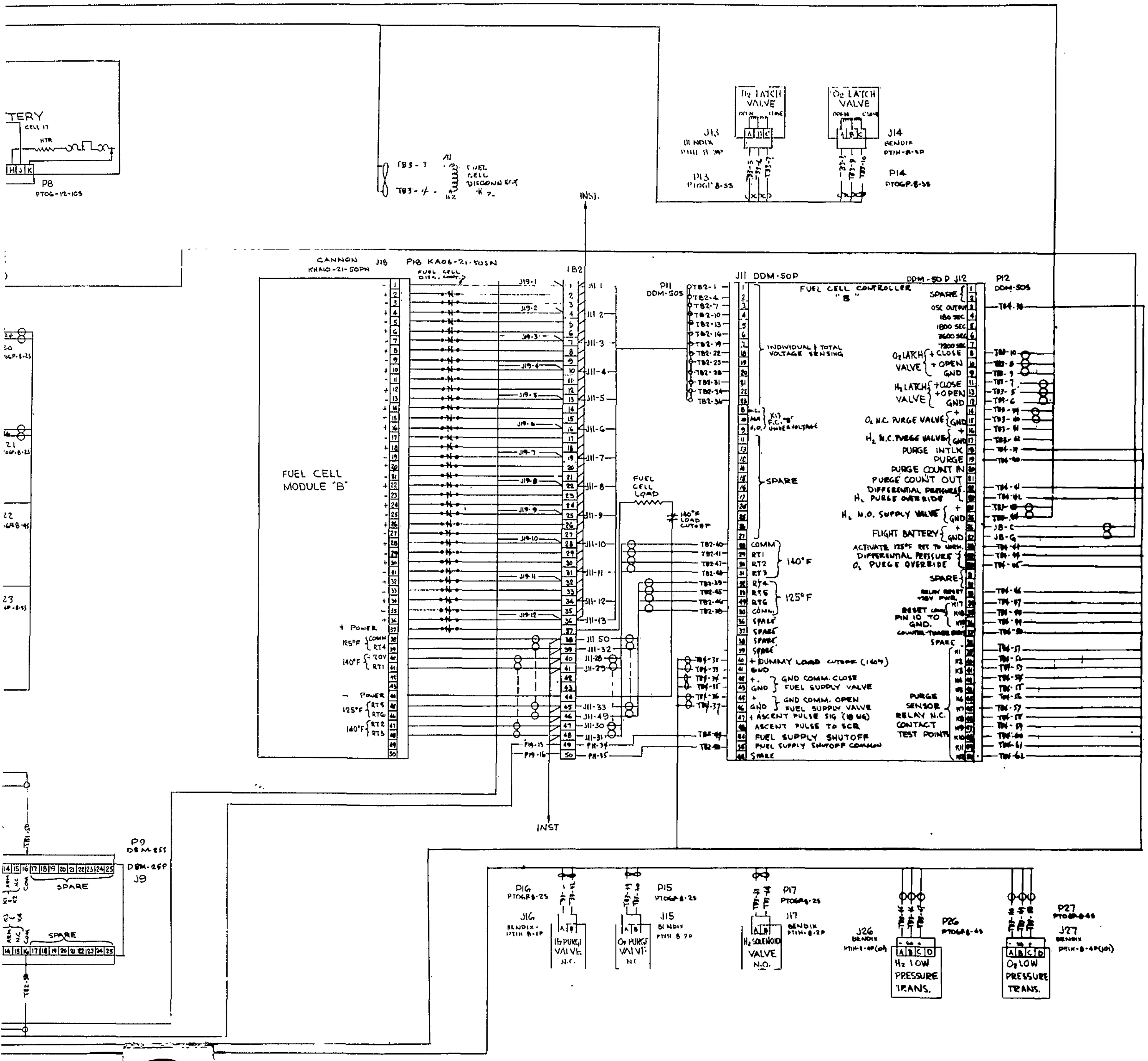
TB-4
160°F. LOAD CUTOFF
GND. COMMAND-CLOSE FUEL SUPPLY VALVE
GND COMMAND-OPEN FUEL SUPPLY VALVE
9 SEC. OSC.
PURGE INTLK.
PURGE SIGNAL
DIFF. PRESS. H_2 PURGE OVERRIDE
DIFF. PRESS. O_2 PURGE OVERRIDE
F.C.C. RESET
PURGE SENSOR RELAY - N.C. CONTACT
F.C.C. A
F.C.C. B.
+ 28 V. NORMAL STANDBY
0 V. PURGE U.V.
TB3
FUEL CELL SHUTDOWN
ELEC. DISC. AUX. RELAYS 1 & 2 (GND. PWR.)
H_2/O_2 FILL/DUMP VALVE CONTROL
H_2/O_2-HIGH/LOW PRESSURE TRANSDUCER INST.
H_2/O_2 DIFF. PRESS. PURGE OVERRIDE SIG.
H_2/O_2 LOW PRESSURE TRANSDUCER INST.
H_2/O_2 DIFF. PRESS. PURGE OVERRIDE SIG.
DDM-50S
P2

1



O2 LATCH VALVE
H2 LATCH VALVE
J4 BENDIX PTIH-8-3P
P4 PTO6P-8-3S
J3 BENDIX PTIH-8-3P
P3 PTO6P-8-3S
FUEL CELL DISCONNECT
FLIGHT BATTERY
J8
P8
FUEL CELL VOLTAGE INST.
DDM-50S P2
CANNON DDM-50P J2
CANNON DDM-50P J1
P1 DDM-50S
FUEL CELL CONTROLLER "A"
TB1
P10
CANNON KHA10-21-50PN J10
INDIVIDUAL & TOTAL VOLTAGE SENSING
FUEL CELL MODULE "A"
FUEL CELL LOAD
140°F LOAD CUTOFF RELAY
J20 BENDIX PTIH-8-2P
H2 FILL/DUMP VALVE N.C.
J21 BENDIX PTIH-8-2P
O2 FILL/DUMP VALVE N.C.
J22 BENDIX
H2 HIGH PRESS. TRANS.
J23 BENDIX
O2 HIGH PRESS TRANS.
PURGE SENSOR RELAY N.C. CONTACT TEST POINTS
FUEL CELL TEMP. INST.
P7
J7 BENDIX PTIH-8-2P
H2 SOLENOID VALVE N.O.
P5
J5 BENDIX PTIH-8-2P
O2 PURGE VALVE N.C.
P6
J6 BENDIX PTIH-8-2P
H2 PURGE VALVE N.C.
P24
J24 BENDIX
H2 LOW PRESS TRANS.
P25
J25 BENDIX
O2 LOW PRESS TRANS.
FAILURE SENSORS
SPARE
FUEL SUPPLY SHUTOFF CONTROLLER
J19 DBM-25S
P19 DBM-25P

2



3

Figure 2-26. DTV Internal Connection Wiring Diagram

voltage ratings where the increase in physical size can be easily accommodated. Optimization of the size and weight of the unit can be accomplished by utilization of magnesium-lithium alloy material in place of aluminum and reduction of the number and size of the chassis parts through different manufacturing techniques.

2.8.2 Fuel Supply Shutoff Controller

The circuit design of the FSSC appears adequate. However, testing in a temperature chamber at high and low temperatures was not accomplished during this period, and only a preliminary product design was completed. Future effort should include further development testing for finalization of the FSSC circuitry and the subsequent product design and qualification testing.

2.8.3 Electrical Disconnect

The 36-pole relay selected during Phase Ia, without designing the unit to withstand the Blue Scout vibration levels, is probably not adequate for flight. Further development of a unit utilizing this or a similar relay is necessary. It is also desirable that the electrical disconnect relay be of a latching-type in order that all electrical power to the vehicle and within the vehicle while on the launch stand be zero for certain phases in the pre-launch assembly and checkout, e.g., during squib installation and launch pad RFI testing.

SECTION 3

FUEL SUPPLY SUBSYSTEM

H. Marderness

3.0 FUEL SUPPLY SUBSYSTEM

3.1 DESIGN ACTIVITY

3.1.1 Subsystem Requirements

The subsystem requirements are as follows:

- Must be reliable.
- Must provide for charging and storing the gases in the gas storage tanks.
- Must provide the capability of quickly dumping the gas from the system in the event of an emergency.
- Must provide sufficient fuel storage for a 7-day mission at full electrical load.
- Must supply the fuel gases to the fuel cell modules at a specified pressure and with a minimum pressure difference between the two fuel gases as supplied to the fuel cell module.
- Must provide for shut-off of the fuel supply to one module in the event of fuel cell module malfunction so that the experiment may be continued on the properly operating fuel cell module.
- Must provide an effective and compatible means of purging foreign gases from the fuel cell module.
- Must provide means for determining the performance of the fuel supply subsystem.
- Must provide a signal for overriding the purge timer in the fuel cell controller in the event the differential pressure between the fuel gases at the inlet of the fuel cell module is excessive. This condition could occur with a sea level static reference pressure, with the fuel cell module operating at no electrical load if the pressure regulator leakage deteriorates and if the purge timer would drift to a longer purge time on the hydrogen side.
- Must provide interfaces with the Pneumatic Ground Service Package, Fuel Cell Controller, Fuel Cell Module and Water Tank.

- Must be suitable for oxygen and hydrogen service.
- Must be capable of withstanding all the environmental requirements.
- Must provide means for ground checkout and test.
- Must provide means near the fuel cell module inlet for introduction of nitrogen or the fuel gases if desired.

3.1.2 Subsystem Design

The mechanization of the fuel supply subsystem is depicted on the subsystem schematic, Figure 3-1. The subsystem consists of the following components and hardware for meeting the subsystem requirements of paragraph 3.1.1:

- Reliability is treated in paragraph 3.1.3.
- The fuel gases are charged and dumped via the Fill/Dump Valve. This valve is energized open during charging. When the subsystem is charged, the Fill/Dump Valves are de-energized, sealing off the gas. In the event the gas is to be dumped, the Fill/Dump Valve is energized, permitting the escape of the gas.
- The capability of storing sufficient fuel is provided by the two gas storage tanks.
- The fuel gases supplied to the fuel cell module are each regulated to 15 $\pm$ 0.5 psig by pressure regulators.
- In the event of a fuel cell module malfunction as sensed by the Fuel Cell Controller from fuel cell module instrumentation, the Fuel Cell Controller will command the Fuel Control Valves closed to avoid circumstances which might result in system damage and to conserve fuel so the experiment may be continued with the properly functioning fuel cell module.
- The need to purge the fuel cell module, as sensed by the Fuel Cell Controller from fuel cell module instrumentation, is relayed to the six Purge Control Valves which are energized for the duration of the purge as controlled by the Fuel Cell Controller. The gas flow and pressure requirements associated with the purge are determined by the Purge Orifices and the time duration of the purge.

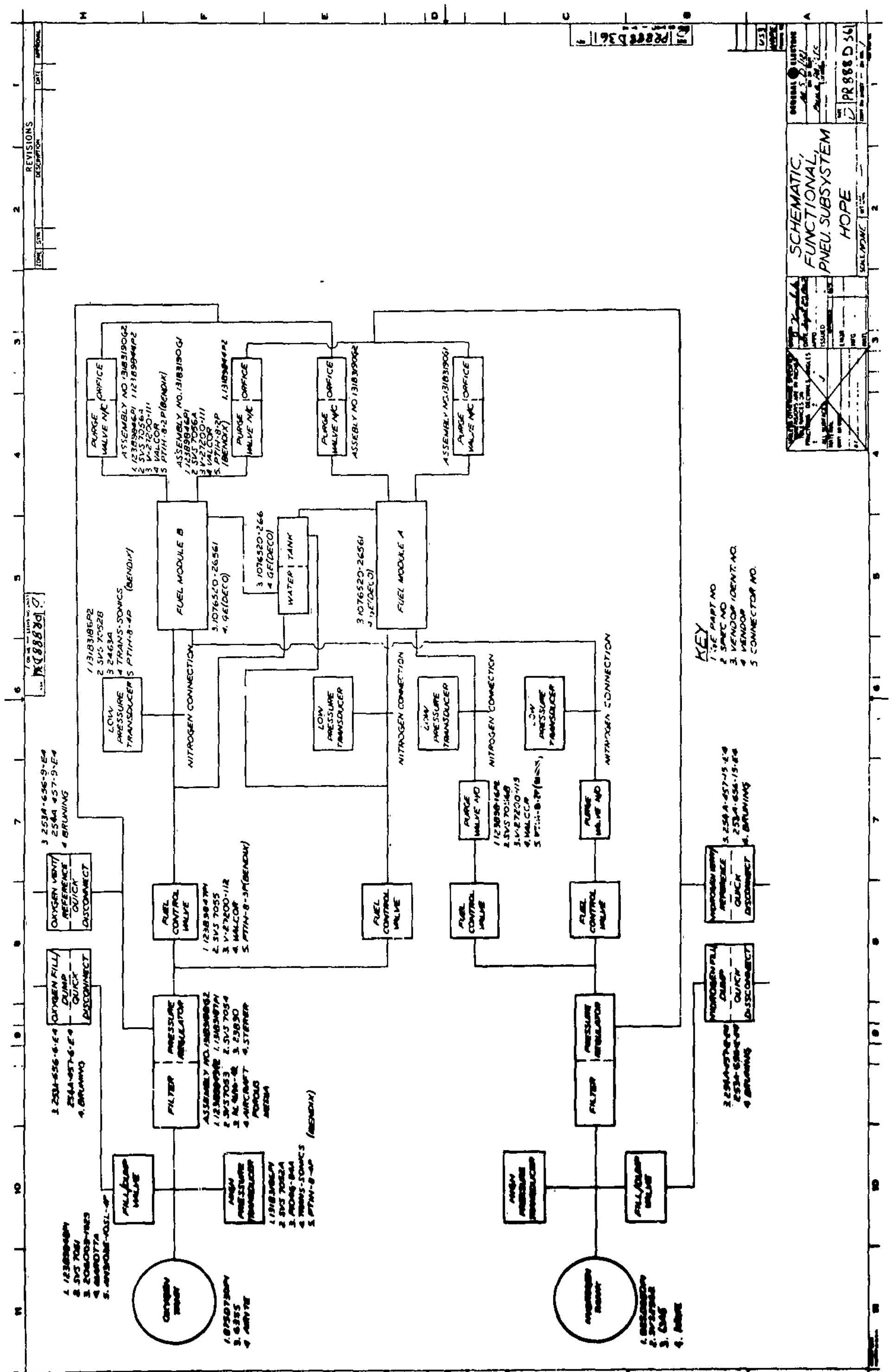


Figure 3-1. Schematic, Functional Pneumatic Subsystem (HOPE)

- The performance of the Fuel Supply Subsystem is indicated via the two high pressure and the four low pressure transducers. The high pressure transducers indicate the rate of fuel expended. The low pressure transducers indicate proper fuel supply to the fuel cell module and proper gas pressures during purging.

- The signal for the differential pressure override on the purge timer is provided by the low pressure transducers.

- Interfacing with the Pneumatic Ground Support Package (PGSP) is provided via the four Quick Disconnects, with the Fuel Cell Controller via the electrical connectors and with the fuel cell module and water tank via flared tube connections.

- Suitability for oxygen and hydrogen service is obtained by proper selection of materials and proper cleaning procedures.

- The capability of withstanding the various environments is obtained by procuring suitably designed components and judiciously configurating the subsystem into the spacecraft structure.

- Means for ground checkout at simulated orbit conditions are provided via the Vent/Reference Quick Disconnects.

- Means for possible introduction of nitrogen or the fuel gases near the fuel cell module inlet are provided via the four nitrogen connections.

In addition, the following interconnecting hardware is used for tieing the components of the subsystem together:

- Tubing - Steel for the high pressure portion (upstream of the pressure regulator) of the subsystem and aluminum tubing for the low pressure portion (downstream of the pressure regulator) of the subsystem.

- Tube Fittings - Steel for the high pressure portion of the subsystem and aluminum for the low pressure portion of the subsystem.

- "Voi-Shan" Metal Seals - Soft metal seals placed in the flared tube connections to minimize the risk of leakage from irregularities in the sealing surfaces of the tube flare and the mating surface on the component or fitting.

- "0" Rings - Elastomer seals for sealing connections to the components.

- Flurolube - Lubricant suitable for oxygen service for lubricating the "0" rings and threads to avoid galling.

The subsystem requirements and design, as translated into component requirements and component configurations, are reflected in the component specifications and drawings; and for the interconnecting hardware in the form of standard parts and/or material specifications as shown in Table 3-1. Copies of the drawings and specifications are included in Appendix 3A Providing, in conjunction with the Fuel Cell Controller, the proper flow and pressure transients to purge the fuel cell module is one of the most important functions of the Fuel Supply Subsystem. As high differential pressures between the two fuel gases in the fuel cell module must be avoided, careful consideration had to be given to this aspect in designing the components involved during purging. The prime consideration, of course, was to design the subsystem to most effectively purge the fuel cell module on the basis of accumulated fuel cell module experience. The following relates the work done in arriving at a suitable purge technique and design:

- An initial effort in the Phase Ia program was to define a purge technique that would satisfy the requirements for the fuel cell module with maximum simplicity in the fuel supply and electrical controls.

- The scheme initially devised was to provide an orifice upstream and downstream of the module on both the hydrogen and oxygen sides to control the pressure in, and the flow through the module during a combination technique of flush and vent purging and to provide the electrical signal to the hydrogen and oxygen purge valves simultaneously and for a specific time period. An analysis was made to determine the appropriate size of the orifices. The four orifices (for one fuel cell module) were then made and tested with a simulated fuel cell module (tank) in preparation for tests with an actual fuel cell module. (The analysis and discussion of the testing are presented in Appendix 3B) At this point a design review of the purge technique was held with the Direct Energy Conversion Operation (DECO).

- At this meeting it was decided that the purge technique should be modified in two ways. First, eliminate through (flush) purging on the hydrogen side due to possible damage to the cell membranes from drying. Second, avoid reducing the oxygen pressure during oxygen flushing below 0.5 psi of the normal operating pressure. Only vent

TABLE 3-1

COMPONENT IDENTIFICATION AND PROCUREMENT

ITEM	PART NAME	QTY. REQ'D. PER VEHICLE	GE/MSD PART NO.	GE/MSD SPEC.	VENDOR IDEN-TIFICATION NO.	VENDOR	QUANTITY ORDERED	MATERIAL REQUEST NO.	PURCHASE ORDER NO.	WHEN RECEIVED	SERIAL NO. OF UNITS	PRESENT LOCATION	REMARKS
1.	Quick Disconnect		Used 308A758 for Quotes	Used 308A758 for Quotes		Bruning Co., Lincoln, Nebraska		9711W589	A55231	10/62	None	Storage	All parts except caps were cleaned by vendor.
	A. Oxygen Fill/Dump												
	1) Body (PGSP)	1			253A-656-6-E4		1						
	2) Nose (Vehicle)	1			254A-457-6-E4		1						
	B. Oxygen Vent/Ref.												
	1) Body	1			253A-656-9-E4		1						
	2) Nose	1			254A-457-9-E4		1						
	C. Hydrogen Fill/Dump												
	1) Body	1			253A-656-12-E4		1						
	2) Nose	1			254A-457-12-E4		1						
	D. Hydrogen Vent/Ref.												
	1) Body	1			253A-656-15-E4		1						
	2) Nose	1			254A-656-15-E4		1						
	E. Body Plug	4			255PA-A		4						
	F. Nose Cap	4			250C-A-E4		4						
2.	Valve, Pneumatic - Solenoid, Fill/Dump	2	111C1520P1	SVS3540	206003-1850	Marotta Valve Corp., Boonton, N. J.	2 (1 unit on MR9711N126)	4444A15	A50226	4/62	1037, 1038	1037 - See MR9711N126. 1038 - Used in B/U of Exp. Compartment.	Valve seat being changed to Kel F and "O" rings in contact with gas being changed for improved suitability for Oxygen service. 1038 was to have been RTV for cleaning and expediting.
					206003-1929	"	1 (Rework)	9711N126	A55166	10/62	1037	Storage	Was reworked to incorporate Kel F seat and Viton "O" rings. Went directly to storage after being received.
					206003-1929	"	1 (DTV Spare)	9711W558	A55165	10/62	1420	Storage	Went directly to storage after being received.
			123B9848P1	SVS7051	206003-1929	"	0						Flight hardware.
3.	Gas Storage Tank, Oxygen	1	875D730P1	SVS3006	6335	Airite Prod. Co., Los Angeles, Calif.	3			Phase I	1013, 1014 1015.	Storage	Must be cleaned for oxygen service. Suitability for oxygen service must be established.
4.	Gas Storage Tank, Hydrogen	1	825D650P1	SVS2562	6335	Airite Prod. Co., Los Angeles, Calif.	3			Phase I	0015, 0016, 0017	Storage	Must be cleaned.
5.	Transducer, Pneumatic - Pressure (High)	2	131B2845P1	SVS3543	P104G-84A	Trans-Sonics, Burlington, Mass.	2	4444A17	A15606	4/62	36773, 36774	36773 - Storage. 36774 - Used in B/U of Exp.	36774 was to have been RTV for cleaning and checking.
							1	9711W559	A55192	10/62	35749	Compartment. Storage.	Was dimensionally checked but not functionally tested.

TABLE 3-1

COMPONENT IDENTIFICATION AND PROCUREMENT (Cont'd)

ITEM	PART NAME	QTY. REQ'D. PER VEHICLE	GE/MSD PART NO.	GE/MSD SPEC.	VENDOR IDEN-TIFICATION NO.	VENDOR	QUANTITY ORDERED	MATERIAL REQUEST NO.	PURCHASE ORDER NO.	WHEN RECEIVED	SERIAL NO. OF UNITS	PRESENT LOCATION	REMARKS
			131B3186P1	SVS7052A	P104G-84A	"	0						Flight Hardware.
6.	Filter, Pneumatic	2	127B5989P1	SVS3216	AC4696-4	Aircraft Porous Media, Glen Cove, L. I., N. Y.	2	Procured from OAO Program.		8/62	1, 2.	1 - Storage 2 - Used in B/U of Exp. Compart-ment.	
					AC4696-42	"	1	9711W560	A55168				Has "O" ring external seal and inlet fitting for flanged tube connection.
			123B98499	SVS	AC4696-42	"	0						Flight Hardware.
7.	Regulator, Pneumatic - Pressure	1 1	131B2846P1	SVS3545	20660	Sterer Engrg. Co., N. Hollywood, Calif.	2 2 (3 units MR9711W565)	4444A00	653853	4/62	1, 2.	P1, S/N 1, used for B/U of Exp. Other units RTV on MR9711W565	Returned to Vendor for incorporation of revised pressure settings and reliability improvements.
		2	131B3187P1 131B3187P1	SVS7054 SVS7054	23830 23830	" "	3	9711W565	A55182				Flight Hardware.
8.	Valve, Pneumatic - Solenoid, Fuel Control	4	123B9847P1 123B9847P1	SVS7055 SVS7055	V27200-112 V27200-112	Valcor Engrg. Co., Kenilworth, N.J.	6 0	9711W564	A55179				Flight Hardware.
9.	Valve, Pneumatic - Solenoid, Purge Con-trol	2	123B9846P2	SVS7056B	V27200-115	Valcor Engrg. Co., Kenilworth, N.J.	3	9711N123	A55167				Change in inlet fitting to bulkhead type fitting desired; 123B9846P3.
			123B9846P2	SVS7056B	V27200-115		0						Flight Hardware - 123B9846P3 if change DTV hardware.
10.	Transducer, Pneu-matic - Pressure (Low)	4	131B2845P2	SVS3544	2463A	Trans-Sonics, Burlington, Mass.	6	4444A19	A15606	4/62	36775 thru 36780	36779 used in B/U of Exp. Com-partment. Other units in Storage.	36779 was to have been RTV for cleaning & checking.
			New Dwg.	SVS7052B	2463A	"	0						Flight Hardware. New MSD Dwg. to show anti-rotation pin.
11.	Valve, Pneumatic - Solenoid, Purge Con-trol	4	123B9846P1	SVS7056A	V27200-111	Valcor Engrg. Co. Kenilworth, N.J.	6	9711W563	A55180				
			123B9846P1	SVS7056A	V27200-111		0						Flight Hardware.
2.	Orifice	2	123B9844P1	None	None	MSD	12	9711W585	DWO N457	9/62		Storage	Four pieces drilled with 0.0225 orifice.
		2	123B9844P2	None	None	MSD	Blanks						

TABLE 3-1

COMPONENT IDENTIFICATION AND PROCUREMENT (Cont'd)

ITEM	PART NAME	QTY. REQ'D. PER VEHICLE	GE/MSD PART NO.	GE/MSD SPEC.	VENDOR IDEN-TIFICATION NO.	VENDOR	QUANTITY ORDERED	MATERIAL REQUEST NO.	PURCHASE ORDER NO.	WHEN RECEIVED	SERIAL NO. OF UNITS	PRESENT LOCATION	REMARKS
15.	Flared Fitting Seals	*	None	None	VSF1015CT4	Vol Shan Mfg. Co. Culver City, Calif.	100	9711N129	A43750	9/62	None	Storage.	For Sealing flared tube connections. *Exact Quantities to be established after B/U complete.
16.	"O" Ring	*	None	None	904-17007	W.B. Gallagher, Conshohocken, Pa.	50	9711N128	A43751	9/62	None	Storage.	Viton A. *Exact Qty. to be established after B/U complete.
		1	None	None	906-17007	"	0						For plug in oxygen tank.
17.	Fluorolube Grease	---	None	None	GR-362	Hooker Electro-Chemical Co., Philadelphia, Pa.	1 lb.	9711N130	A47307	9/62	None	Storage.	For lubrication of "O" rings and threads.
13.	Tubing - Steel	Approx. 21	None	None	MIL-T-8506 (.25" x .020")	Tube Sales, Bala Cynwyd, Pa.	24-Feet	9711N127	A43749	9/62	None	Storage. Most of it used in Exp. Comp. B/U.	
				None	None	"	24-Feet	9711U052	A44254	10/62	None	Storage.	
	Tubing - Aluminum	Approx. 60 Feet	None	None	WW-T-789 6061 Cond 0 (.25" x .020") *	"	48 Feet	9711N127	A43749	9/62	None	Storage. Most of it used in Exp. Comp. B/U.	
		60 Feet	None	None	"	"	60 Feet	9711U052	A44254	10/62	None	Storage.	
14.	AN Fittings	2 1 1 Exact quantities to established after B/U complete.	None	None	AN804-4C AN806-4C AN806-6C AN815-4C AN815-4D AN818-4C AN918-4D AN824-4C AN824-4C AN824-4D AN827-4D AN832-4D AN924-4C AN924-4D AN929-4D MS20819-4C MS20619-4D	Dee Aircraft Supply, Albertson, L.I., N.Y.	0 1 1 6 0 14 80 2 25 6 6 0 6 4 14 80	9711W591	A43754	9/62	None	Storage - Some items are in the Exp. Comp.	Obtained some items from Stock Room.

purging would be used in the hydrogen side which would consist of shutting off the fuel supply upstream of the module and opening the purge valve downstream of the module, allowing flow only for a period that would result in the pressure decreasing 2 ± 0.5 psi. An orifice would be used downstream of the module to provide an appropriate and repeatable time period for accomplishing the hydrogen vent purge. Flush purging would be used on the oxygen side for a 45 ± 5 second period with the flow being controlled by a downstream orifice such that the total flow would be that associated with replacing essentially one module volume, 2000 ± 200 CC, of oxygen. An analysis was made to determine the appropriate orifice sizes and time duration for the hydrogen purge. Tests were then conducted to verify the analysis. (The analysis and discussion of the testing are discussed in Appendix 3C.)

- Figure 3-1 shows the Fuel Supply Subsystem with the latest purge technique. The two purge solenoid valves on the hydrogen side were added to shut-off the hydrogen supply during hydrogen purging. The valves were added rather than using the fuel control valves for turning the hydrogen fuel supply off and on during the purge for reliability considerations in that a simple normally open valve would be more reliable than a latching valve. The orifice blanks will be drilled in the Missile & Space Department (MSD) Pneumatics Laboratory to acquire the desired flow versus pressure drop characteristic. The orifices will than be installed in and lockwired to the purge valve to protect the orifice from contamination by utilizing the outlet filter of the purge valve as the orifice inlet filter.

- The purge system as described in Appendix 3C was expected to meet all requirements except for the oxygen and hydrogen pressures during sea level static operation with a 14.7 psia reference pressure when the hydrogen pressure is expected to drop 4 psi rather than 2 psi and the oxygen pressure is expected to drop 1 psi rather than 0.5 psi. This difficulty was overcome by incorporating the pressure differential override function previously described. A set of orifices was made and tested at DECO with a module. On the oxygen side the flow was somewhat low. The required purge time on the hydrogen side was appreciably longer than expected, due to the tubing and the pressure drop in the purge valve; also, the difference between the simulated module, 25 in.^{3} tank, and the actual module was considerable. The appropriate orifice sizes and the purge time cannot be finalized until the module is tested with the Development Test Vehicle (DTV) Fuel Supply Subsystem. The purge time was subsequently

modified; however, this has no effect on the Fuel Supply Subsystem and is discussed in section 2 above.

3.1.3 Reliability

There are two major areas of concentrated effort for acquiring Fuel Supply Subsystem reliability, namely, the area of design and test at the component and subsystem levels, and in the area of manufacture; in particular, cleaning and handling.

3.1.3.1 Design Aspects

At the component level the major considerations were as follows:

- Use components that are identical with or similar to components used on other MSD programs. If this is not feasible, use off-the-shelf-type items to the extent possible.
- Review the design with particular emphasis on reliability features and incorporate appropriate design modifications. In particular, the following was done:
  - Filters were incorporated in the inlet and outlet ports as integral parts of the purge and fuel control valves as the majority of solenoid valve problems stem from contamination.
  - An "0" ring was incorporated in place of the teflon seal for controlling external leakage from the purge control valves due to a potential cold flow problem with teflon as a seal.
  - The filter and pressure regulator are assembled upon receipt from the vendor to protect the pressure regulator from contamination.
  - The orifice and purge control valves will be made an assembly so the valve filter will act as the inlet filter for the orifice.
  - The metal seal that controls external leakage from the filter is being replaced by an "0" ring to avoid the hazards of metal seals.
  - The flareless fitting on the inlet of the filter is being replaced by a flared fitting to avoid possible leakage problems with the flareless fitting.

- Coordinate MSD and Vendor Functional Tests to assure that each component is performing properly as delivered by the Vendor. This would also reduce cost and time required at MSD to make the components available for use in the vehicle. It would further lessen the possibility of contaminating the components at MSD during test. Based on the similarity of the HOPE components with existing hardware, basically no testing other than the Functional Tests were planned; however, where it was deemed appropriate, special tests were conducted or planned.

The above items are elaborated upon in Table 3-2.

At the subsystem level the major considerations were as follows:

- Simple design.

- Design the subsystem using the most reliable components available for each function at the expense of adding components, if appropriate, rather than using the same component to perform additional functions, and considering redundancy features. In particular:

  - The addition of two normal open purge valves for shutting off the hydrogen supply during hydrogen purging rather than using the fuel control valves due to the increased inherent reliability of a simple normally open solenoid valve over that of a latch-type solenoid valve.

  - The use of the low pressure transducer outputs to override the hydrogen purge in the event theduration of the purge time as programmed by the fuel cell controller became too long.

  - The mounting of the components so that the axis of the component most susceptible to vibration is in the transverse plane of the spacecraft.

  - The use of the Voi Shan metal seals to acquire increased reliability regarding leakage.

- Conduct appropriate tests on the Fuel Supply Subsystem prior to System (DTV) Testing. In particular:

  - DECO and MSD purge tests.

TABLE 3-2

COMPONENT RELIABILITY INFORMATION

ITEM	PART NAME	SIMILARITY WITH EXISTING HARDWARE	TEST NAME	FUNCTIONAL TESTS CONDUCTED BY VENDOR	FUNCTIONAL TESTS CONDUCTED BY MSD	OTHER TESTS CONDUCTED BY MSD	REMARKS
1.	Quick Disconnects	Off-the-shelf items	Proof Pressure Leakage	No No	Planned Planned	None	All parts except caps were cleaned. Parts use Viton-A "O" ring seals. Connectors are indexed to avoid cross-connection of lines to the vehicle. Parts are aluminum.
2.	Valve, Pneumatic - Solenoid, Fill/Dump	Off-the-shelf item.	Proof Pressure Leakage Pressure Drop Operating Voltage Electrical Power Insulation Resistance Hipot Response	Yes Yes No Yes Yes Yes Yes No	S/N's 1037 and 1038, as originally received, were both tested to all tests except Press. Drop, Hipot and Response. Both units passed all tests.	S/N 1037, as originally received, operated properly and passed leak test after being energized continuously for 1 hour at 28 VDC and then being cycled 60 times with 5 seconds on per minute with 3250 psig inlet pressure exhausting through an orifice to ambient	The valve is of the balanced poppet design so that it will function with either the inlet or the outlet at the higher pressure except that there is a slight unbalance such that the valve will open without being energized when the outlet pressure exceeds the inlet pressure by approximately 1700 psi. This requires that the inlet port be toward the gas storage tank. The material of the seat and the "O" rings in contact with the fuel gases were changed from Nylon to Kel F and from Buna N to Viton to improve the suitability of the valve for oxygen service.
3.	Gas Storage Tank, Oxygen	Identical with Nimbus Tank	Proof Pressure Leakage		Planned Planned	Planned to conduct tests to verify suitability for oxygen service.	Four units were tested on Nimbus for proof pressure, volume change with pressure, pressure cycling, leakage and burst pressure. All tanks performed satisfactorily. Burst pressures were 5350 to 5700 psig.
4.	Gas Storage Tank, Hydrogen	Identical with Advent Tank	Proof Pressure Leakage		Planned Planned	None	Two tanks were tested on Advent for proof pressure, volume change, 1000 cycle endurance, leakage, acceleration (7g & 2g), vibration (5-100 cps, 2.5g; 100-300 cps, 3g; 300-2000 cps, 5g). These units plus one new unit were burst tested. All tanks performed satisfactorily. Burst pressures were 5640 to 5850 psig.
5.	Transducer, Pneumatic - Pressure (High)	Similar to Nimbus. Off-the-shelf item. Qualified on Nimbus.	Proof Pressure Leakage Winding Resistance Contact Resistance Calibration Insulation Resistance Hipot	Yes Yes Yes No Yes Yes Yes	S/N's 36773 and 36774 tested and passed all tests except not checked for Hipot.	None	
6.	Filter, Pneumatic	Identical with OAO except for changing to flared inlet fitting and "O" ring seal in place of metal seal for control of external leakage	Proof Pressure Leakage Pressure Drop Rating	Yes Yes Yes Yes	S/N's 1 and 2 were both tested to all tests except for rating. Both units passed all tests.	None	The OAO leakage limit of 0.5 scc/hr was exceeded (1.8 scc/hr) during extreme temperature testing. Tests with an "O" ring showed that leakage was maintained in limits. OAO is planning to change to the "O" ring seal.

TABLE 3-2

COMPONENT RELIABILITY INFORMATION (Cont'd)

ITEM	PART NAME	SIMILARITY WITH EXISTING HARDWARE	TEST NAME	FUNCTIONAL TESTS CONDUCTED BY VENDOR	FUNCTIONAL TESTS CONDUCTED BY MSD	OTHER TESTS CONDUCTED BY MSD	REMARKS
7.	Regulator, Pneumatic - Pressure	The 23830 design is identical with 20 units made for JPL. Similar to OAO low pressure regulator.	Proof Pressure Leakage Regulated Pressure Relief Valve Perf. Response	Yes Yes Yes Yes No	All four units were tested to the first two tests and two units to all tests. Two units had excessive relief valve leakage due to contamination. The faults were cleared by passing a high flow through the relief valve. Both units were out of limits on regulated pressure, relief valve performance and response due to inlet pressure effects. The new specification SVS7054 allows for wider tolerances.	Two units were vibration tested in all three planes while flowing with 2500 psig inlet pressure at vibration levels of 5 to 50 cps, 1.5g; 50 to 500 cps, 7.1g; 500 to 2000 cps, 14 g. Both units performed satisfactorily.	On the OAO program S/N 1, 20660 was used to conduct high and low temperature and acceleration testing. The unit leaked internally, 7 scc/hr after acceleration. It was subsequently used for the preliminary buildup of the Experiment Compartment. An OAO regulator was tested with contamination entrained in the gas. Leakage up to 16 scc/hr resulted. Leakages of this magnitude are not of serious concern for the HOPE program as flows of this low a magnitude would not result except at no electrical load. When proof pressure testing, the reference part must be capped to avoid excessive pressure differentials across the diaphragm. When performing such a test the Reference Part must be opened gradually to bleed off the gas so as not to pressure the diaphragm.
8.	Valve, Pneumatic - Solenoid, Fuel Control	Basic design similar to past OAO design. Identical to units manufactured for other valcor program except changes in material for oxygen service, port configuration and electrical connection.	Proof Pressure Leakage Pressure Drop Operating Voltage Electrical Power Insulation Resistance Hipot	Program was stopped just prior to start of testing.	None	None	Inlet and outlet filters Vitan A "O" rings. Mechanical latch design requiring a short electrical pulse to actuate open or closed to conserve electrical power.
9.	Valve, Pneumatic - Solenoid, Purge Control, (N/O)	Basic design similar to OAO, Nimbus, Advent and 698. Nimbus design qualified. OAO design being qualified. HOPE design is most similar to the OAO design as it has the inlet and outlet filters and the "O" ring seal. It is different from the OAO design only in materials for oxygen service and port and electrical connector configurations plus being normally open rather than being normally closed.	Proof Pressure Leakage Pressure Drop Operating Voltage Electrical Power Insulation Resistance Hipot	Program was stopped just prior to start of testing.	None	None	Inlet and outlet filters. Viton A "O" rings.
10.	Transducer, Pneumatic - Pressure (Low)	Similar to the Nimbus design. Basically an off-the-shelf item. Qualified on Nimbus.	Proof Pressure Leakage Winding Resistance Contact Resistance Calibration Insulation Resistance Hipot	Yes Yes Yes No Yes Yes Yes	All units, except S/N 36779, tested and passed all tests except not tested for Hipot.	None	S/N 36779 was not tested because it was used for buildup of the Experiment Compartment.

TABLE 3-2

COMPONENT RELIABILITY INFORMATION (Cont'd)

ITEM	PART NAME	SIMILARITY WITH EXISTING HARDWARE	TEST NAME	FUNCTIONAL TESTS CONDUCTED BY VENDOR	FUNCTIONAL TESTS CONDUCTED BY MSD	OTHER TESTS CONDUCTED BY MSD	REMARKS
11.	Valve, Pneumatic - Solenoid, Purge Control, (N/C)	Same comments as for item 9 apply except valve is normally open.	Proof Pressure Leakage Pressure Drop Operating Voltage Electrical Power Insulation Resistance Hipot	One unit tested; program was stopped just prior to start of testing other units.	None	None	Inlet and outlet filters. Viton A "O" rings.
12.	Orifice		Pressure Drop vs Flow		Planned	None	Must conduct a test with the fuel module installed in the actual Fuel Supply Subsystem to finalize the orifice size. Orifice definition must then be specified on the orifice drawing for hydrogen and oxygen.
13.	Tubing	Off-the-shelf item	None	None	None	None	Steel - 304 Stainless Steel in the annealed state per MIL-T-8506. Aluminum - 6061 Condition 0 per WW-T-789.
14.	Fittings	Off-the-shelf items	None	None	None	None	
15.	Flared Fitting Seals	Off-the-shelf item	None	None	None	None	Cleaned for oxygen service. Tin plated copper for suitability for Al-Al, Al-Steel, Steel-Steel connections.
16.	"O" ring	Off-the-shelf item	None	None	None	None	Viton A for oxygen service and no rubber cure date.
17.	Fluorolube Grease	Off-the-shelf item	None	None	None	None	Suitable for oxygen service.

- Functional tests with tanks of appropriate volume to simulate the fuel modules.

- Leakage tests.

3.1.3.2 Reliability Analysis

A reliability analysis was completed on the fuel supply subsystem as described herein. The following assumptions were made in analyzing the subsystem:

- The parts selected are similar in quality and design to those used in pneumatic subsystems for MSD programs ADVENT, NIMBUS and OAO. Failure rates for these parts are based on MSD test experience, and field and test experience of other major space industry contractors.

- The fuel supply subsystem will be as shown in Figure 3-1.

- The oxygen and the hydrogen fuel tanks are designed for an ultimate stress of twice the operating pressure. Therefore, in operation, the major failure mode is leakage at the connections.

- Failure of the filter element would not be catastrophic and the major failure mode which would affect proper operation is leakage at the seals.

- Failure in the high pressure and the low pressure transducers would influence telemetry but would not be catastrophic to the fuel supply subsystem so that only leakage failure mode is considered applicable in this case.

- Fill and dump valves do not operate after launch so that the only failure mode would be leakage during the mission.

- Oxygen purge valves operate once per hour maximum, or 168 cycles maximum for the 7-day mission. Hydrogen purge valves go through a maximum of four cycles every two hours maximum or 336 cycles maximum for the 7-day mission. Failure of a purge valve would cause degradation of a fuel cell output or complete failure of a fuel cell.

3.1.3.3 Reliability Computations

Table 3-3 summarizes the parts in the pneumatic subsystem and their failure rates. The reliability computation follows:

$$R_{(Pm)} = e^{-\left[\lambda t_{\substack{\text{(time dependent)} \\ \text{parts}}} + \lambda_{\text{(cyclic parts)}}\right]}$$

$$R = e^{-\left[(.4465 \times 168 \times 10^{-5}) + (814.4 \times 10^{-5})\right]}$$

$$= \underline{\underline{.9911}}$$

3.1.3.4 Manufacturing Aspects

This area involves particular attention toward obtaining a clean and properly assembled fuel supply subsystem in the spacecraft. In particular, the following were major considerations:

- All the main components, valves, pressure regulators, filters and pressure transducers were cleaned by the respective vendors.
- All component testing was done with a 5 micron filter upstream of the component. Protective caps were kept on all ports except during test.
- A single actual component or mockup part was used for buildup of the FuelSupply Subsystem for fabricating the tubing. The actual components were to be returned to the respective vendor for cleaning subsequent to the buildup.
- All tubing, fittings, etc., were to be cleaned at MSD.
- Final assembly of the Fuel Supply Subsystem was to be done in the MSD clean room.

3.1.4 Cost and Weight

Reliability, weight and cost was the selected order of precedence. The cost was given the lowest priority on the basis that cost savings resulting from trade-offs for reliability would quickly be nullified by any problem areas arising; in addition, time delays would result. Because of weight considerations, maximum use was made of light-weight materials, particularly as follows:

TABLE 3-3.

H O P E

FUEL SUPPLY PNEUMATICS

PART	QUAN. (N)	OPERATION		LEAKAGE ONLY	(λ) F.R. (%/1000 HOURS)	$N\lambda$ ($X10^{-5}$)
		HRS.	CYCLES			
Filter	2	168	---	X	.0023*	.0046
Regulator	2	168	---	---	.070	.140
Fuel Control Valve	4	168	---	X	.024*	.096
Low Pressure Transducer	4	168	---	X	.0001	.0004
High Pressure Transducer	2	168	---	X	.0001	.0002
Fill and Dump Valve	2	168	---	X	.0985*	.197
Oxygen Purge Control Valve	2	---	168	---	6.06**	12.12x16.8
Hydrogen Purge Control Valve	4	---	252	---	6.06**	24.24x25.2
Joints	84	168	---	X	.0001	.0084

Total Per Hours = $.4465 \times 168 \times 10^{-5}$

Total Per Cycles = 814.1×10^{-5}

*Leakage failure rate is taken as 50% of part failure rate.

**Failure rate in % per 10^4 cycles.

- **Aluminum alloys were used on valves, filters, etc., wherever possible.**

- **Aluminum tubing was used for the low pressure portion of the subsystem.**

- **A tube wall of .020" was used throughout the subsystem.**

3.2 PROCUREMENT ACTIVITY

The availability of hardware, as provided in the Phase I program, was reviewed as to the adequacy for support of the Phase Ia DTV Test Program. Wherever 50% spares did not exist, additional hardware was ordered which involved placing of purchase orders for one high pressure transducer, three filters, and one fill/dump valve. In addition, purchase orders were placed to rework three of the four pressure regulators to incorporate revised pressure settings and to incorporate changes to enhance the reliability and to rework one fill/dump valve to improve its suitability for oxygen service. Purchase orders were also placed to procure the fuel control and purge control solenoid valves and for the tubing, fittings, "0" rings, etc., for completing the fuel supply subsystem.

MSD worked closely with the vendors to acquire an optimum design for reliability and to insure that proper cleaning procedures were being followed. In addition, vendor and MSD test procedures were coordinated so that a minimum number of functional tests would need to be conducted at MSD. This was done to minimize cost, expedite availability of the parts for assembly into the DTV, and to minimize the risk of contaminating the parts during test.

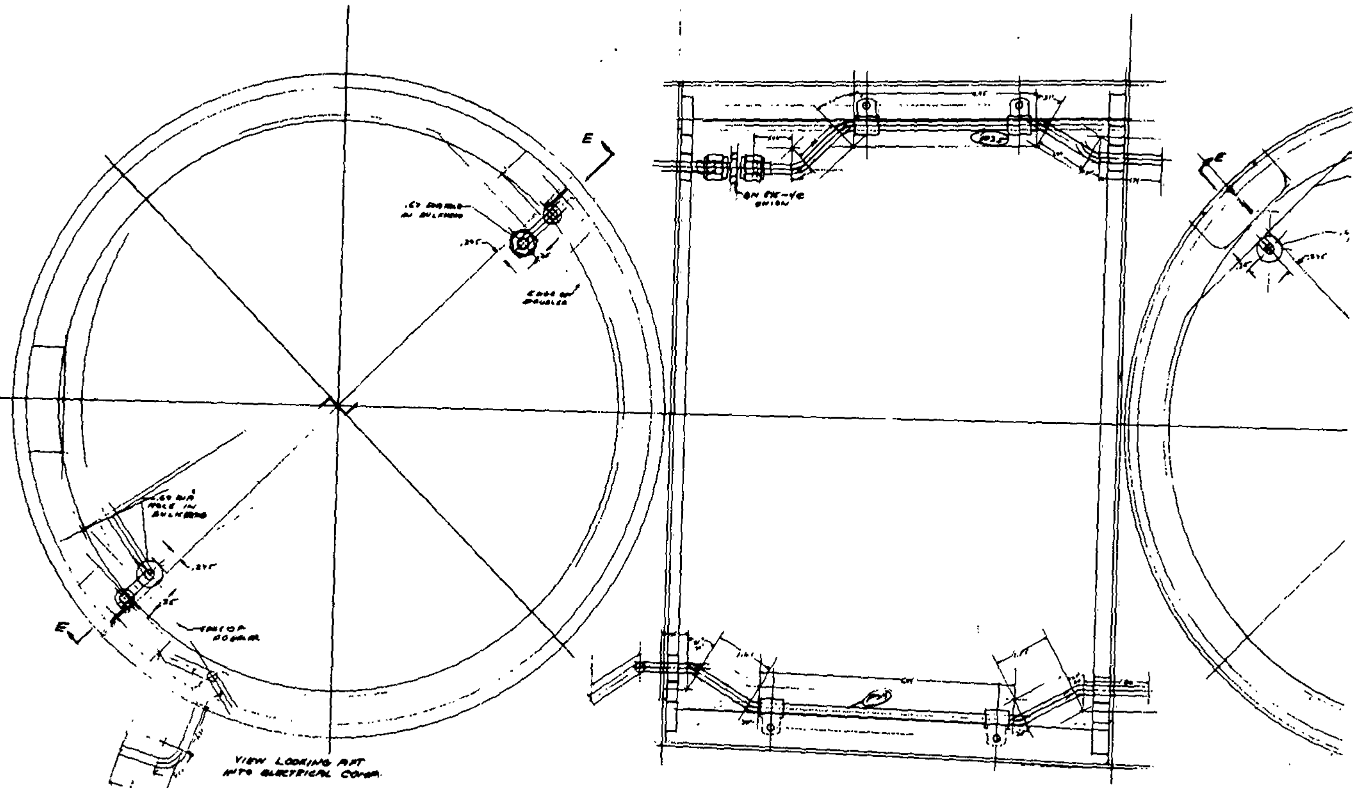
The identification of the hardware and the information relating to procurement is presented in Table 3-1. For completeness, the hardware which was planned for flight is also shown in the tabulation.

3.3 DEVELOPMENT TEST VEHICLE (DTV) ACTIVITY

Figures 3-2a, 3-2b and 3-2c show the mounting location and configuration for the fuel supply subsystem components and the routing and clamping of the tubing. This drawing was used as the basis for building up the Experiment Compartment and for the fabrication of the tubing between the gas storage tanks and the Experiment Compartment.

Past experience indicated that of the two approaches, namely:

- Preparing a layout drawing showing the component mounting and routing and clamping of the tubing, preparing manufacturing

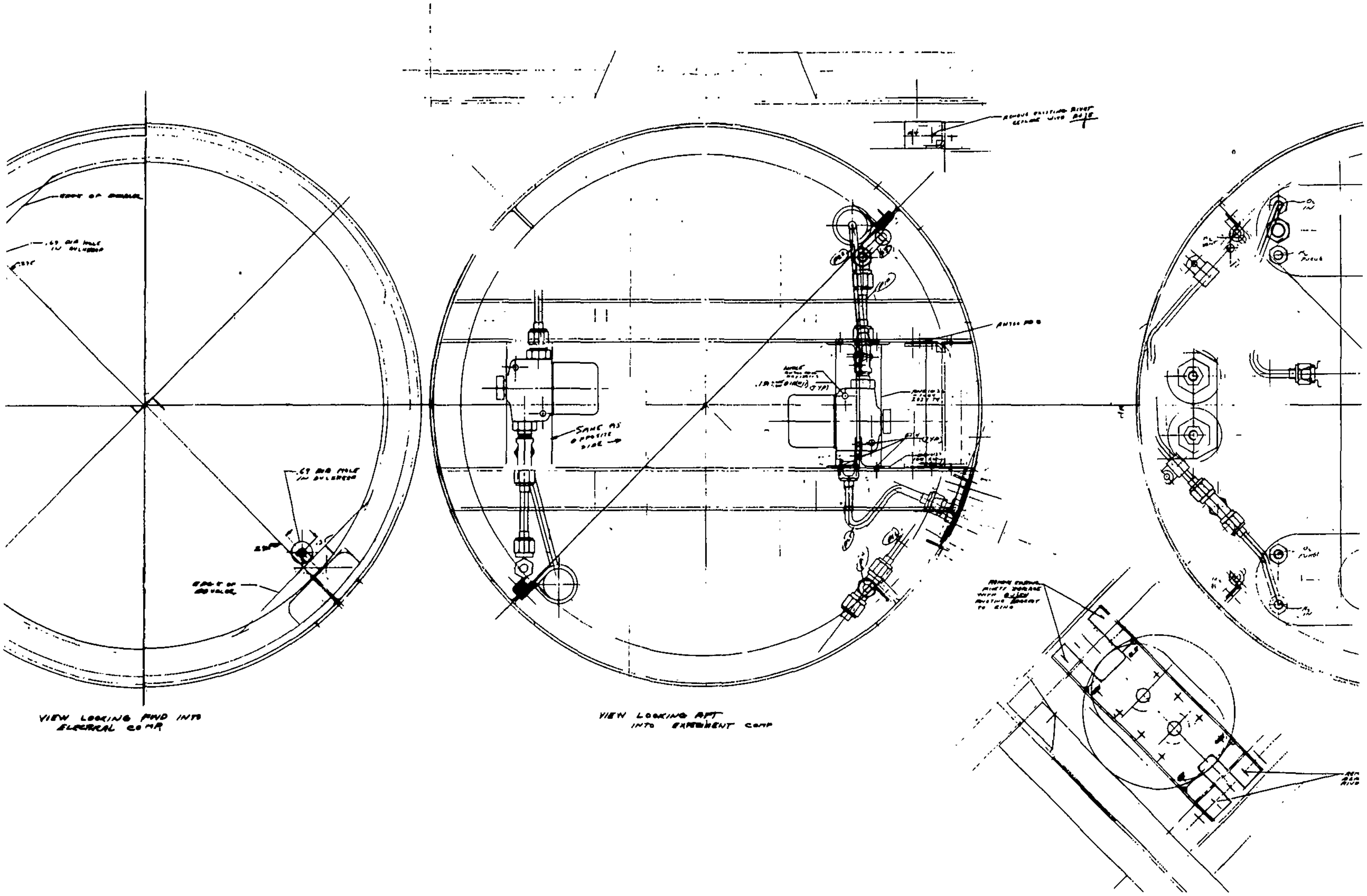


VIEW LOOKING AFT INTO ELECTRICAL COMP.

SECTION E-E

V12

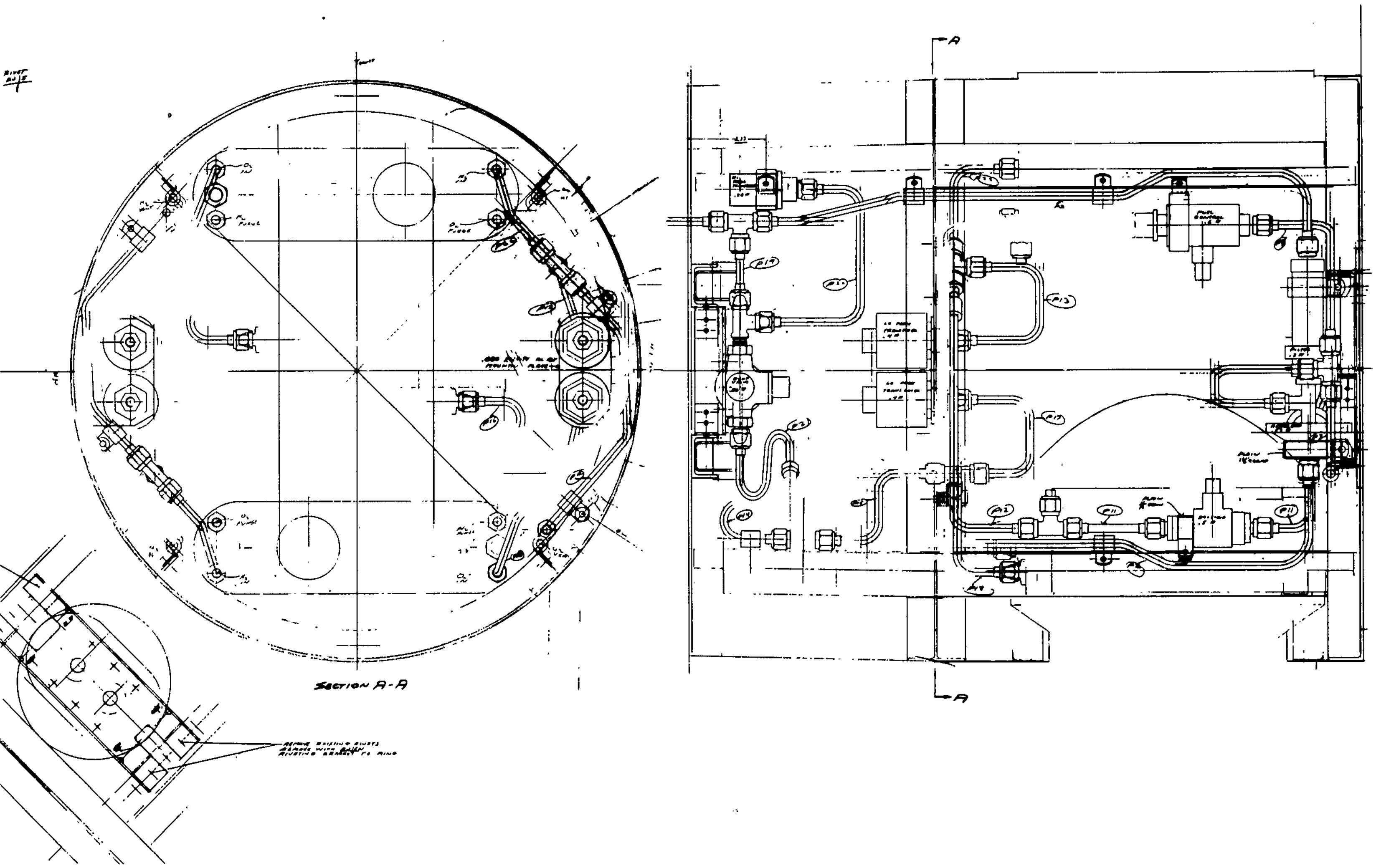
1



VIEW LOOKING FWD INTO ELECTRICAL COMP

VIEW LOOKING AFT INTO EXPERIMENT COMP

2



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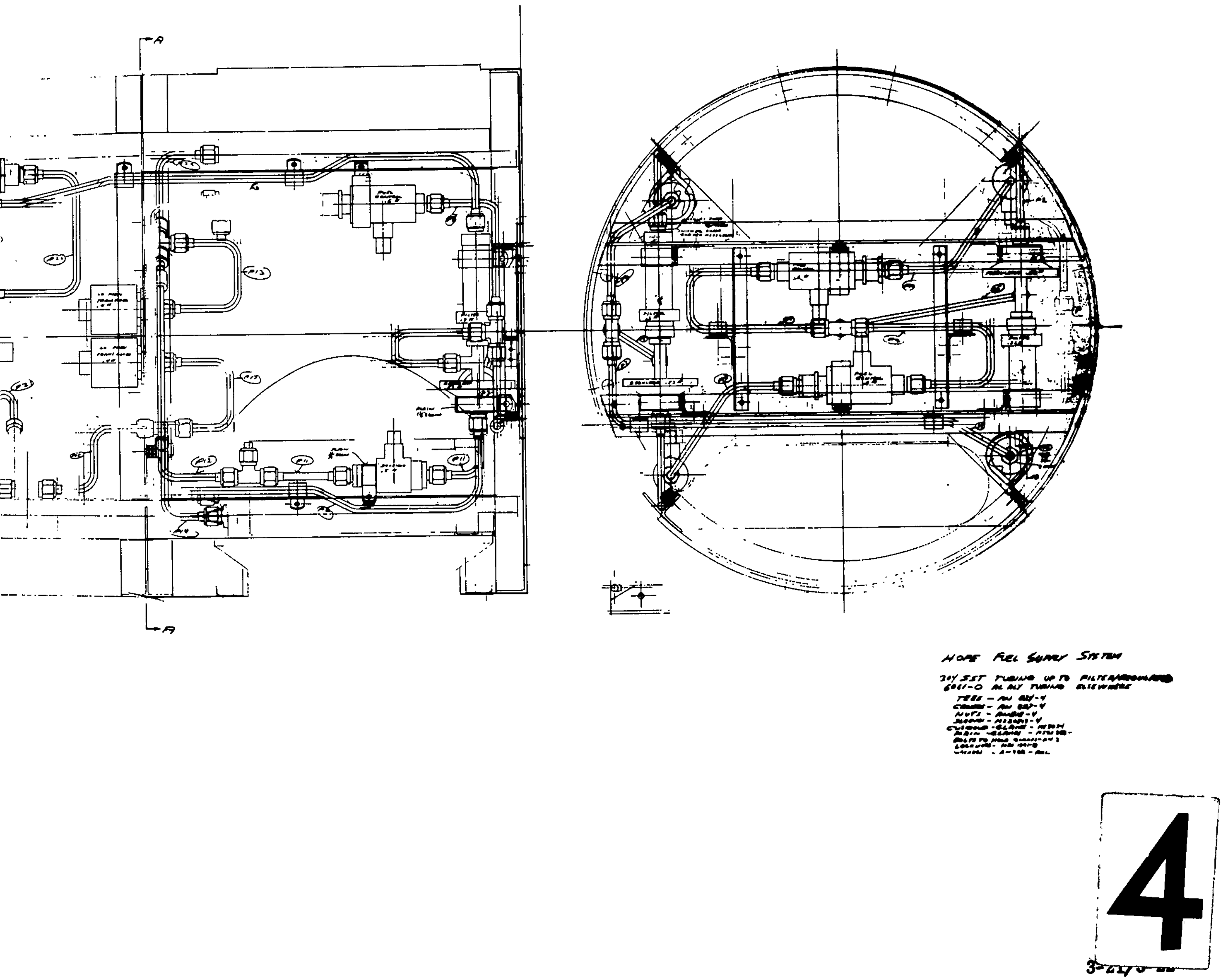
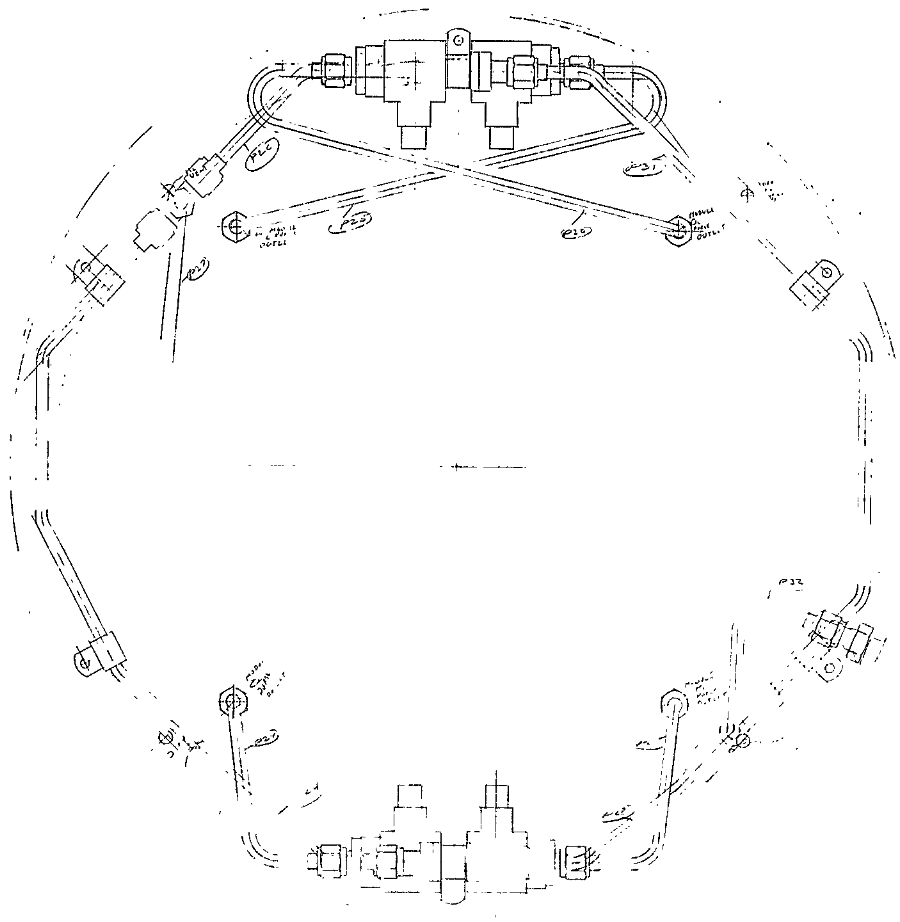


Figure 3-2a. Layout-Pneumatics Installation (HOPE)



1

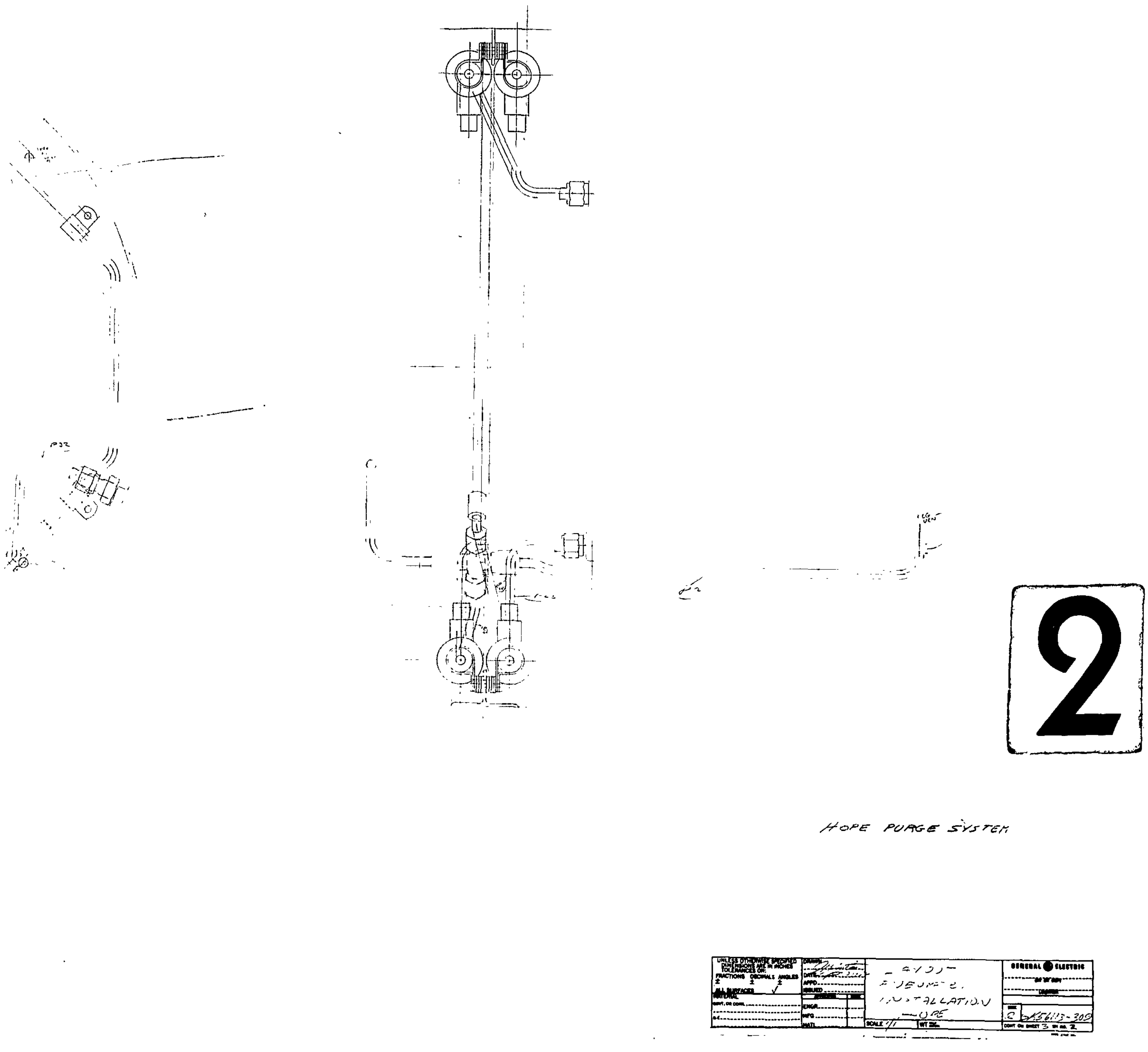
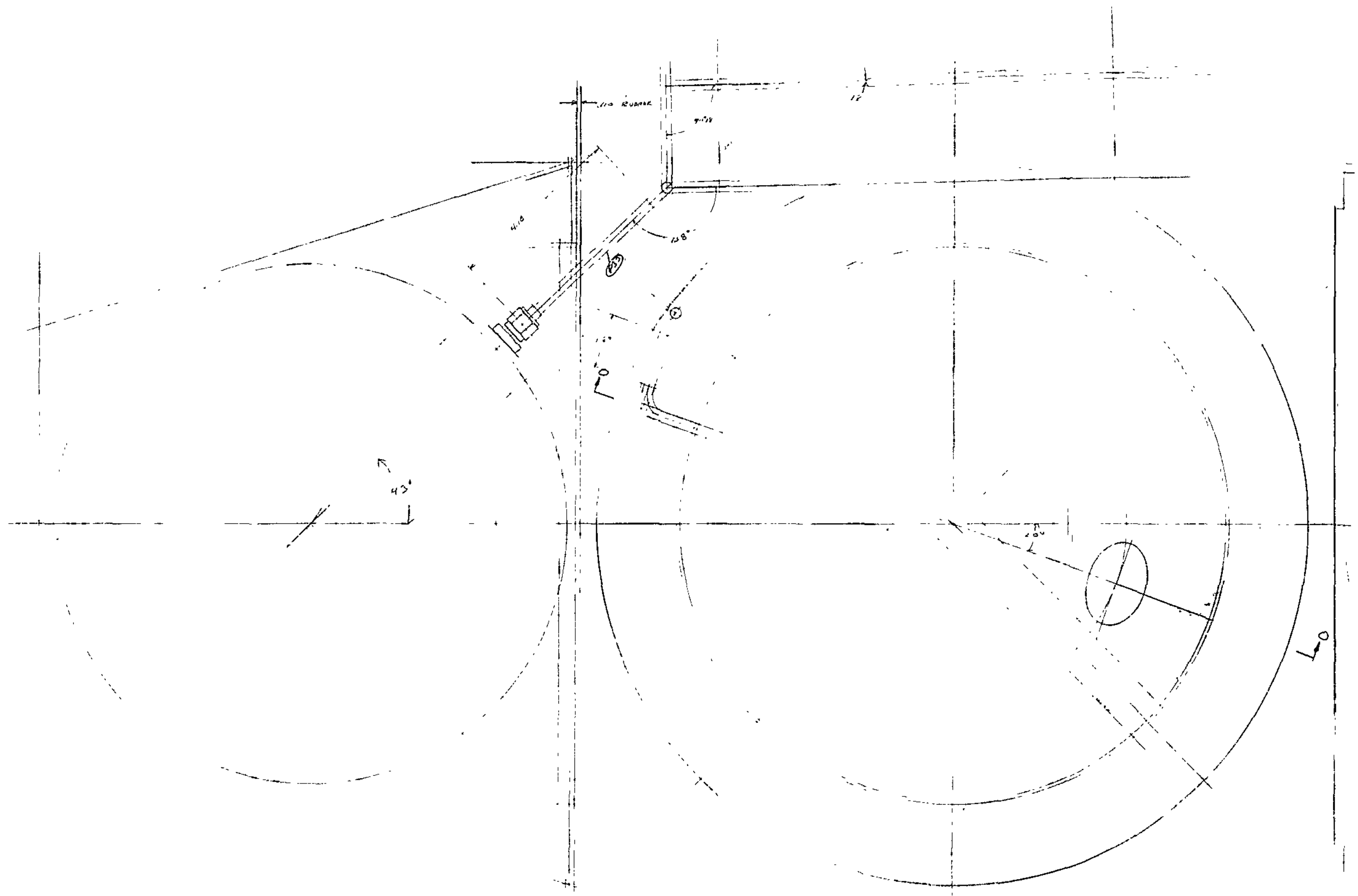


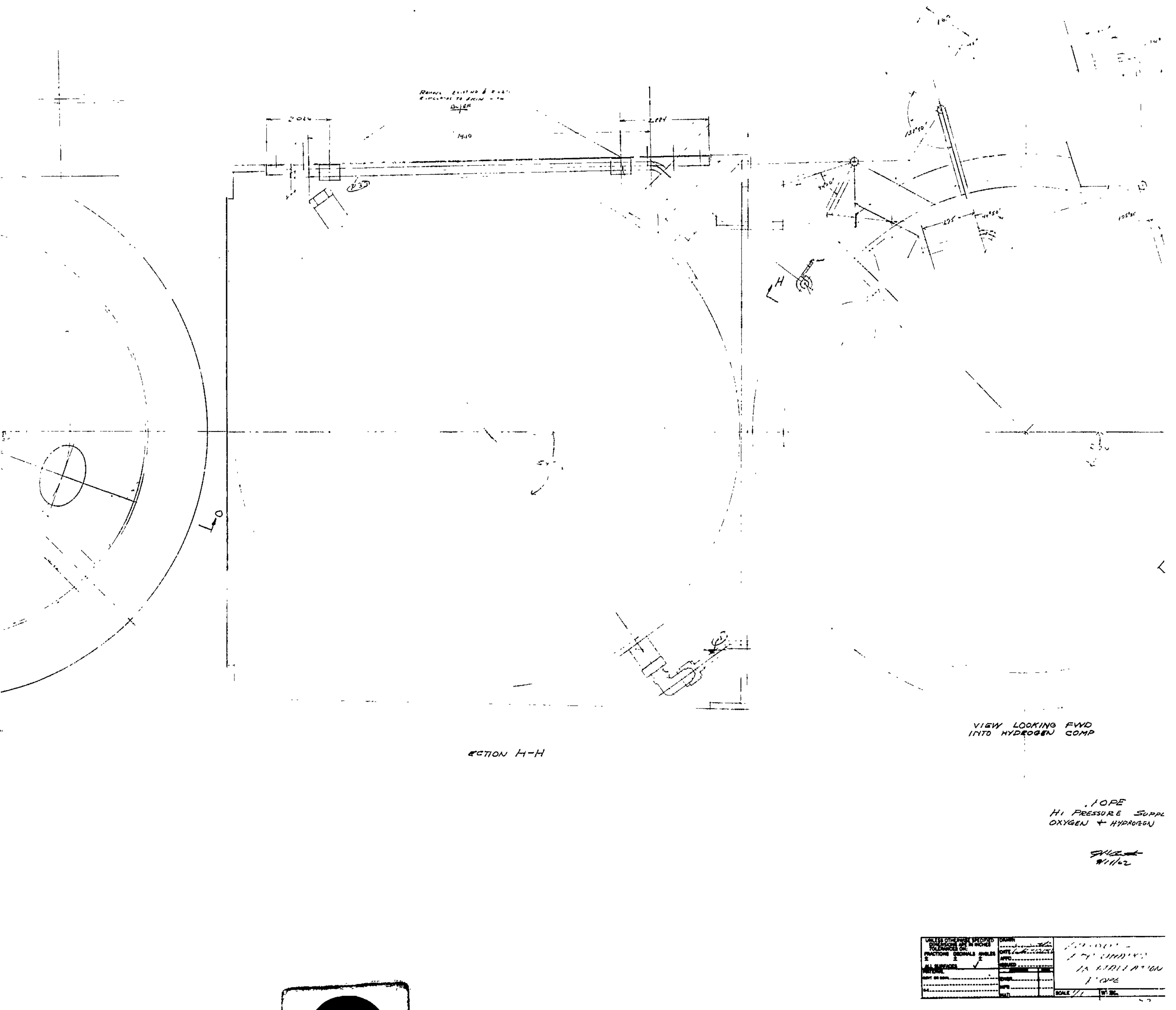
Figure 3-2b. Layout-Pneumatics Installation (HOPE) (Cont'd)



SECTION O-O

VIEW LOOKING FWD
INTO OXYGEN COMP

1



2

Figure 3-2c. Layout-Pneumatics Insta

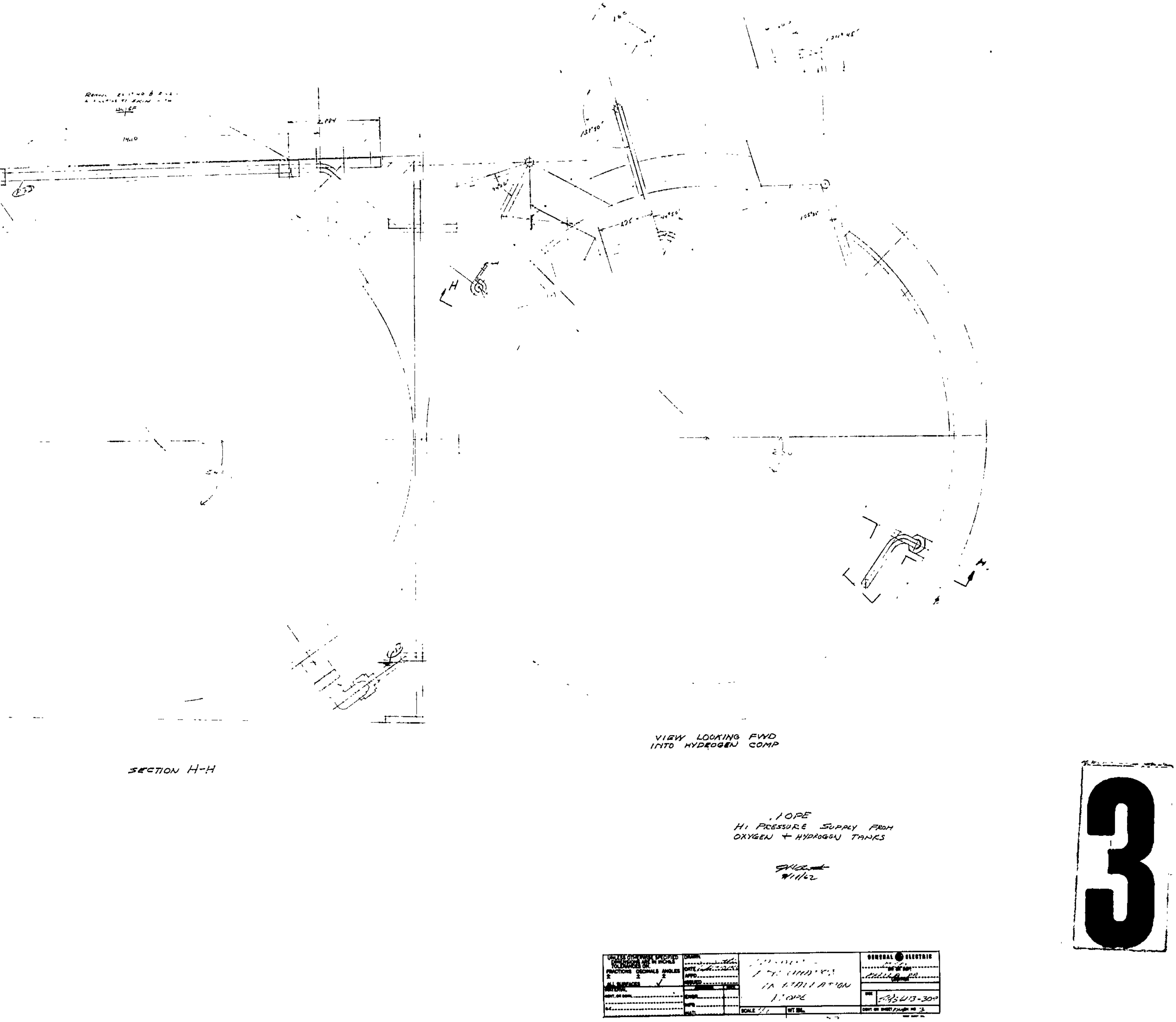


Figure 3-2c. Layout-Pneumatics Installation (HOPE) (Cont'd)

drawings for the tubing, fabricating the tubing, and then building up the compartment; and

. Preparing only the layout drawing.

the latter is the better approach and was used for the Experiment Compartment. As there were only three tubes external to the Compartment, namely, those leading to the gas storage tanks, the former of the two approaches was used for these tubes.

3.3.1 Manner of Performing and Status of the Fuel Supply Subsystem Buildup

The buildup of the Experiment Compartment was started on September 26, 1962. As of October 17, 1962, when work was stopped, 75% of the work for configurating and clamping the tubing was completed. The three tubes leading to the gas storage tanks were completed.

Throughout the buildup period, a Tube Fabricator, experienced in configurating space vehicle pneumatic subsystems, and a Pneumatics Laboratory Technician were employed. One set of actual fuel supply components or mockup parts was used. The work of the Laboratory Technician encompassed interpretation of the pneumatic subsystem layout drawings with regard to routing of tubing and component mounting, relocating the components to different positions as the compartment buildup progressed, modifying the structure to mount some of the components and the tube clamps, aiding in identifying and effecting changes in the configuration as appropriate changes appeared during buildup of the compartment, identifying the tubing with tags and maintaining a record of the compartment buildup proceedings. The tube fabricator bent and flared the tubing and made a card for each tube recording the various lengths and bends so that the tubes could be reproduced at a later date. Photographs showing the Experiment Compartment and tubing to the gas storage tanks in its state when work was stopped are included as Figures 3-3 to 3-14. The fuel control and purge control valve mockups were relocated for the photographs showing the lower end of the compartment.

The tubing which remains to be completed is as follows:

. Tube to the inlet of the oxygen filter using an adapter between the filter and the tube to permit use of a flared tube connection rather than flareless.

. Inlet tubes to each of the two oxygen fuel control valves.

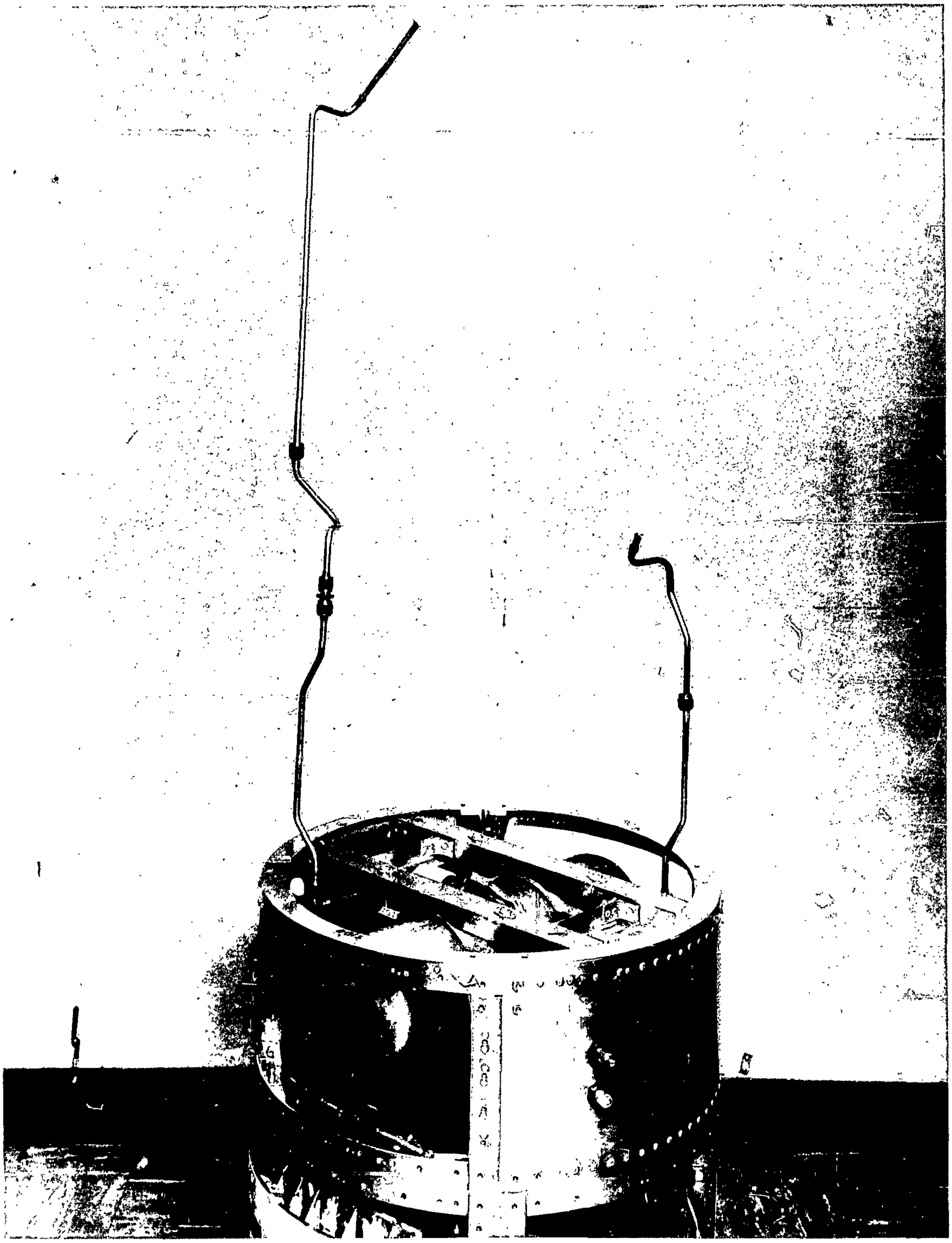


Figure 3-3. Experiment Compartment

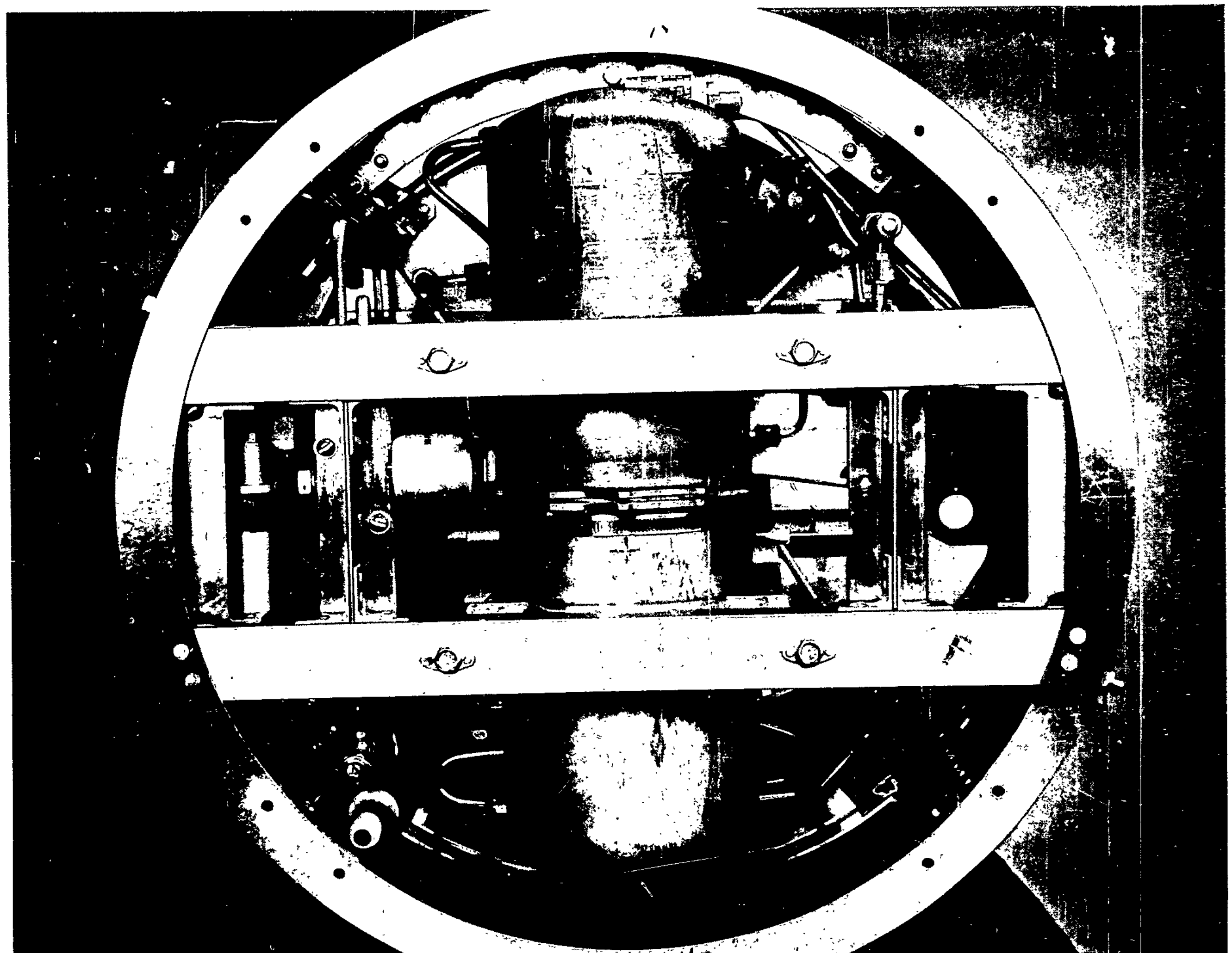


Figure 3-4. Experiment Compartment

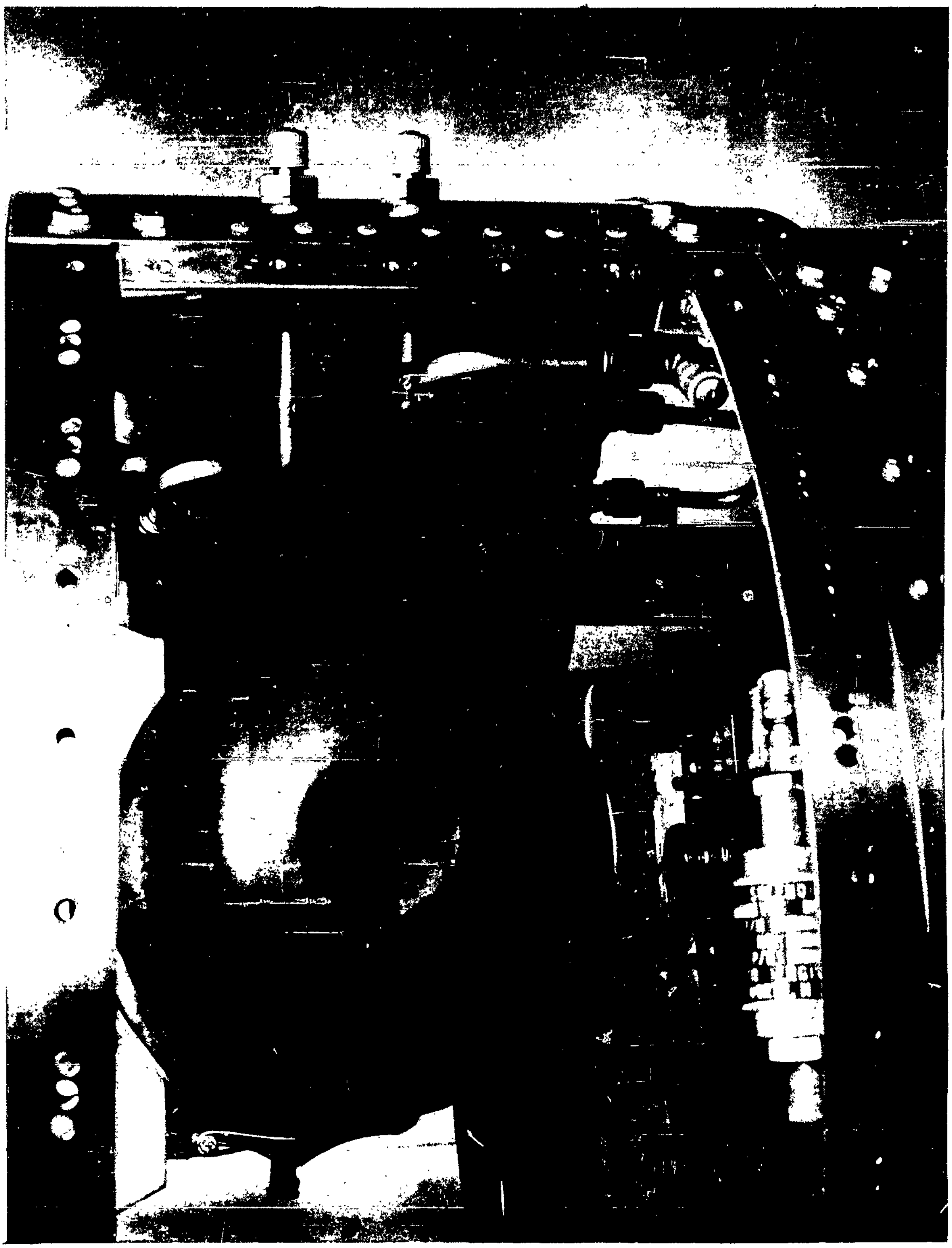


Figure 3-5. Experiment Compartment

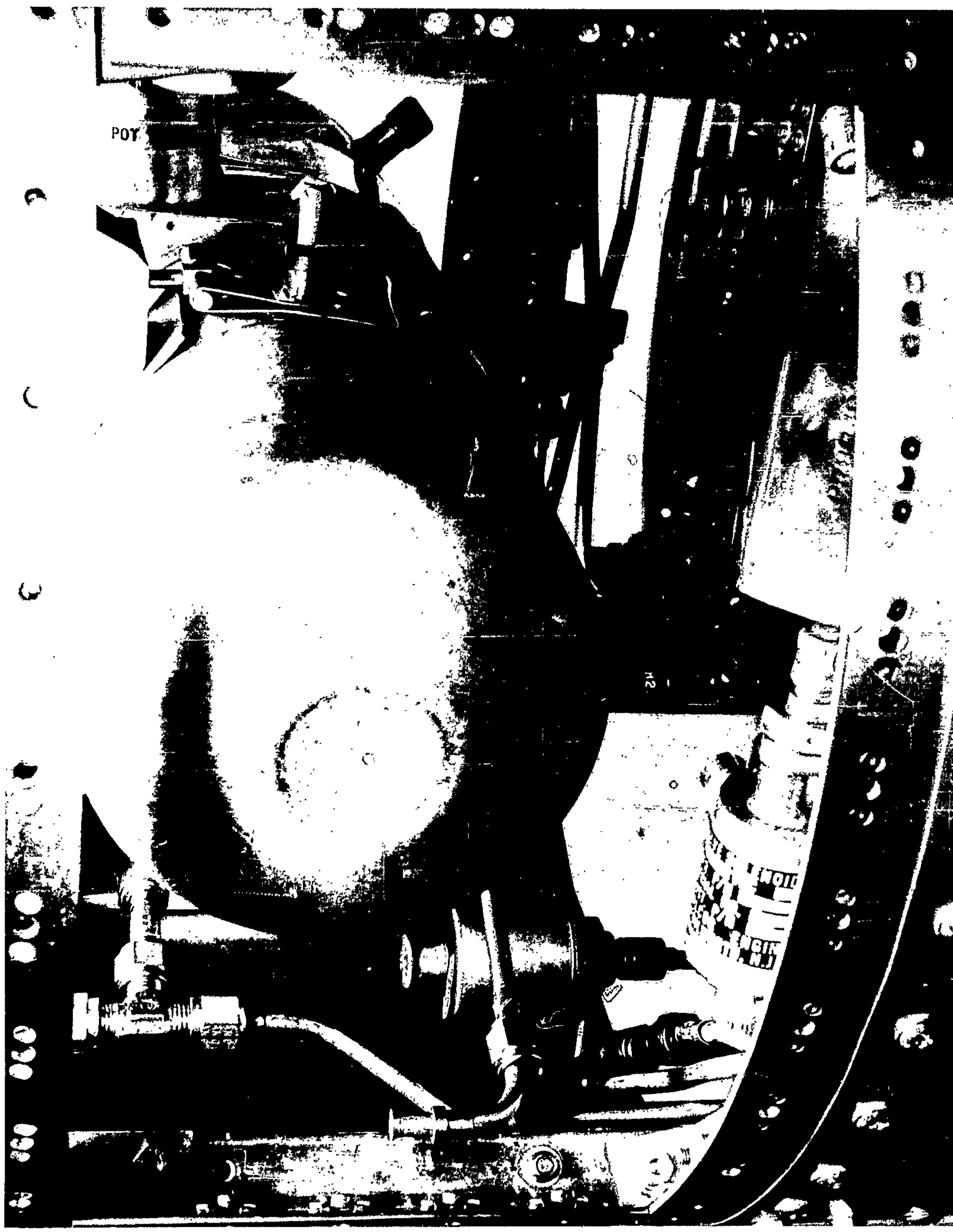


Figure 3-6. Experiment Compartment

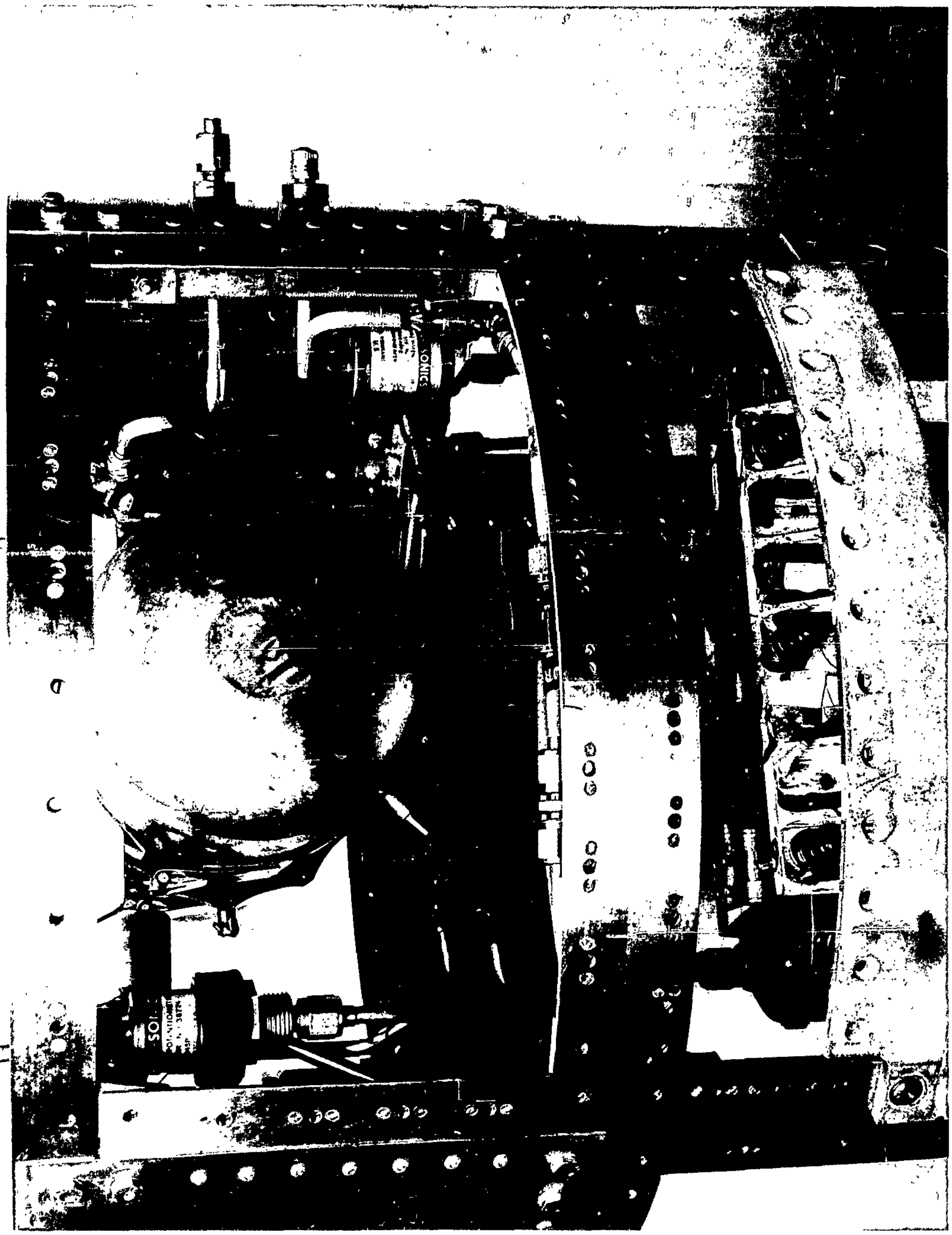


Figure 3-7. Experiment Compartment

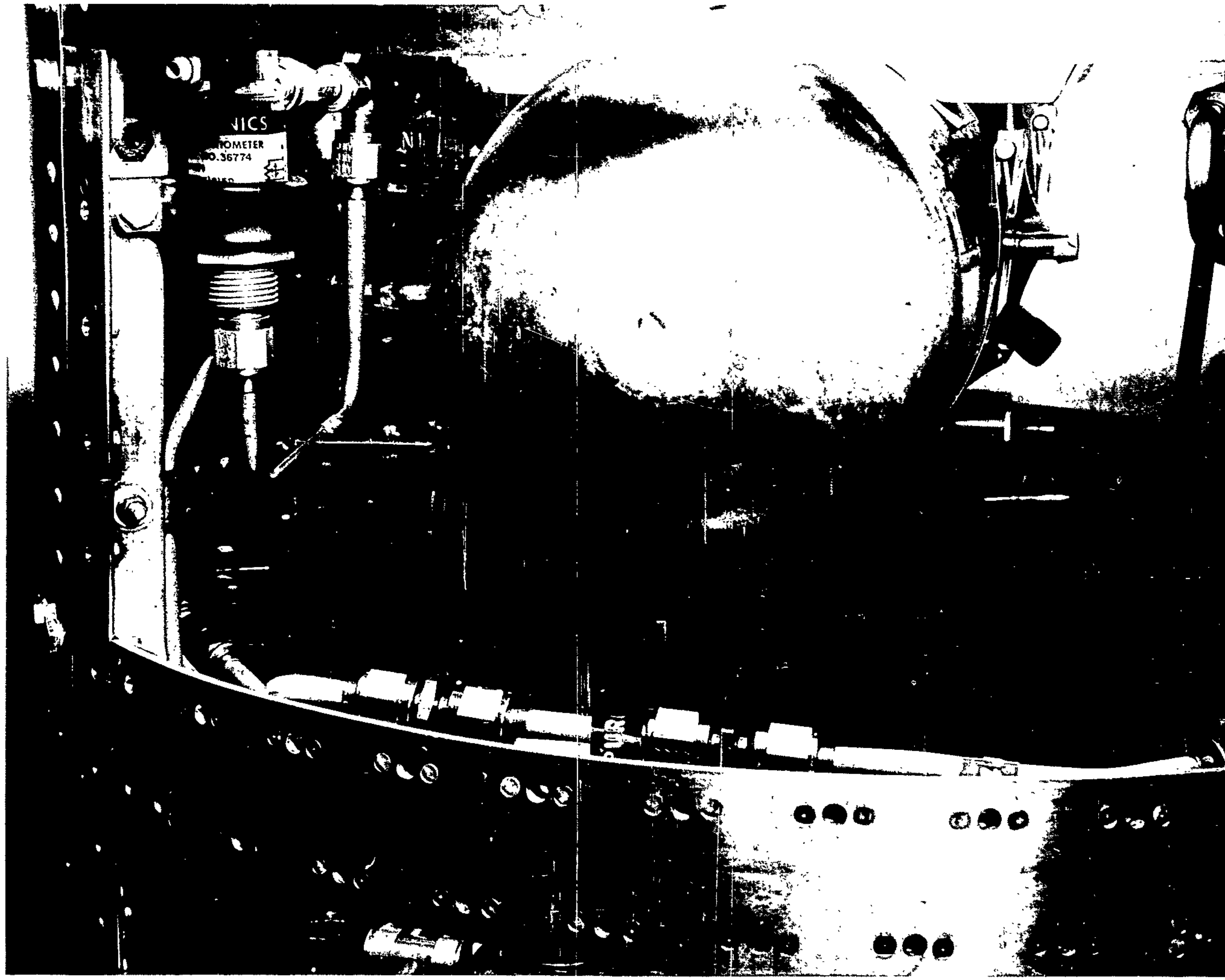


Figure 3-8. Experiment Compartment

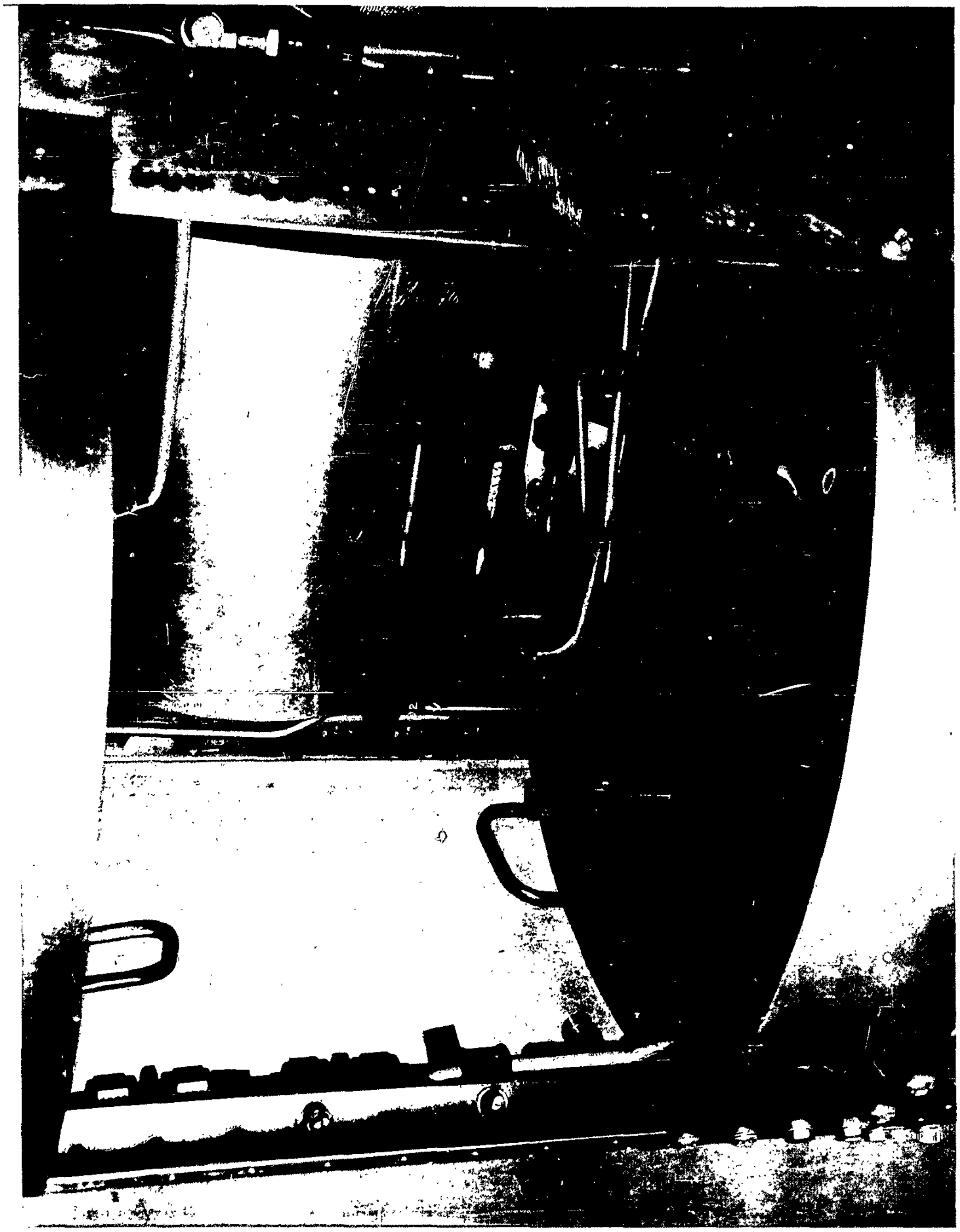


Figure 3-9. Experiment Compartment

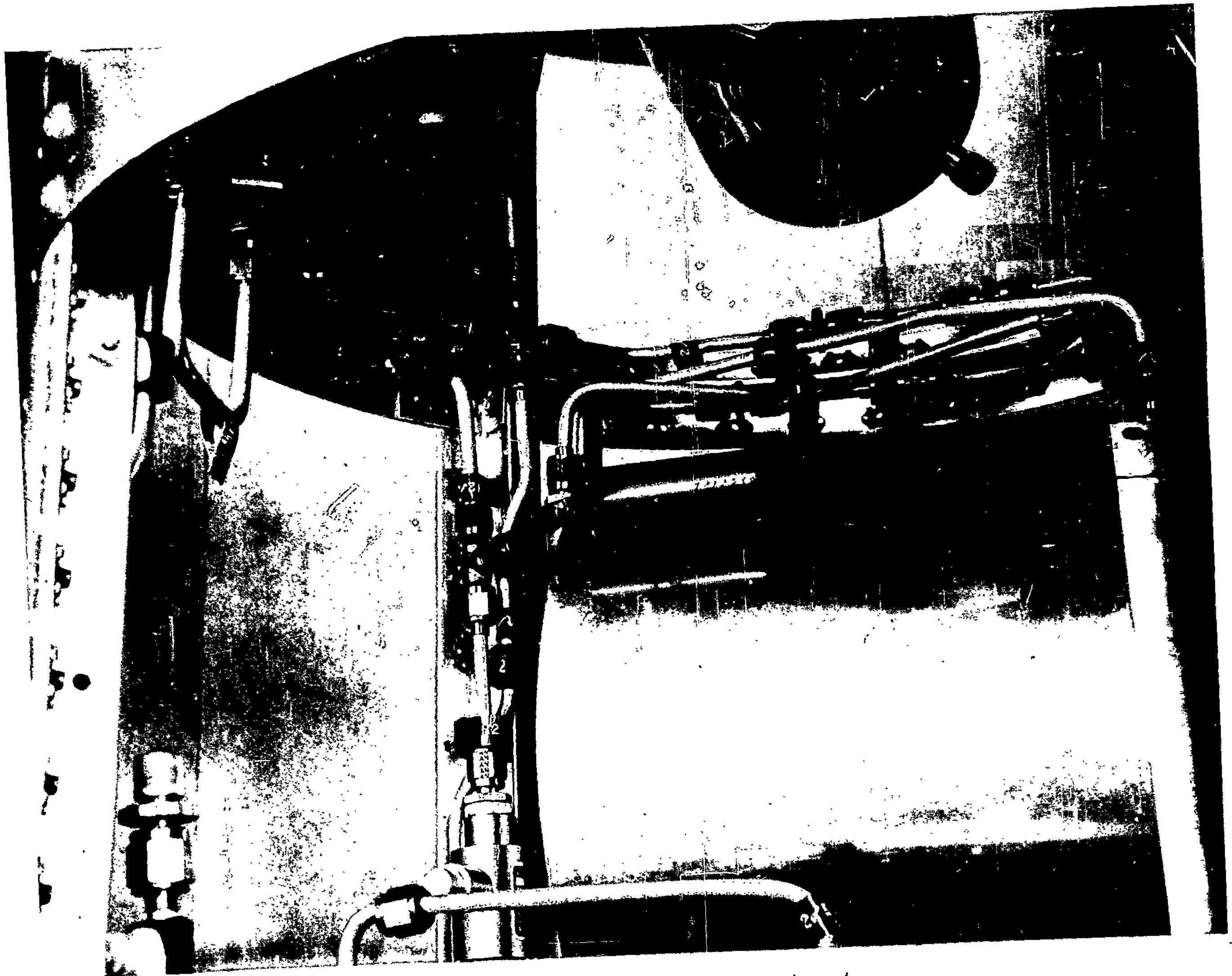


Figure 3-10. Experiment Compartment

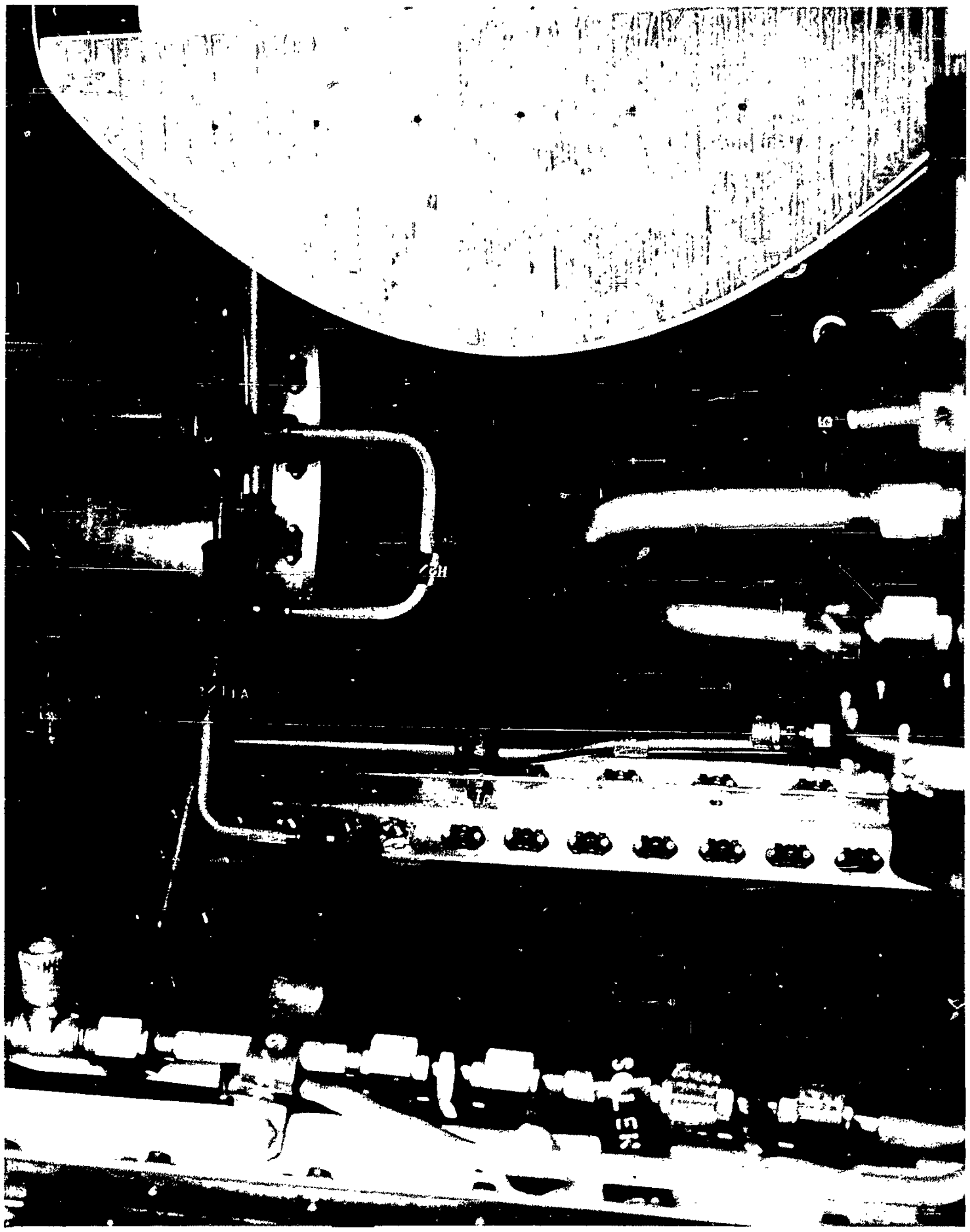


Figure 3-11. Experiment Compartment

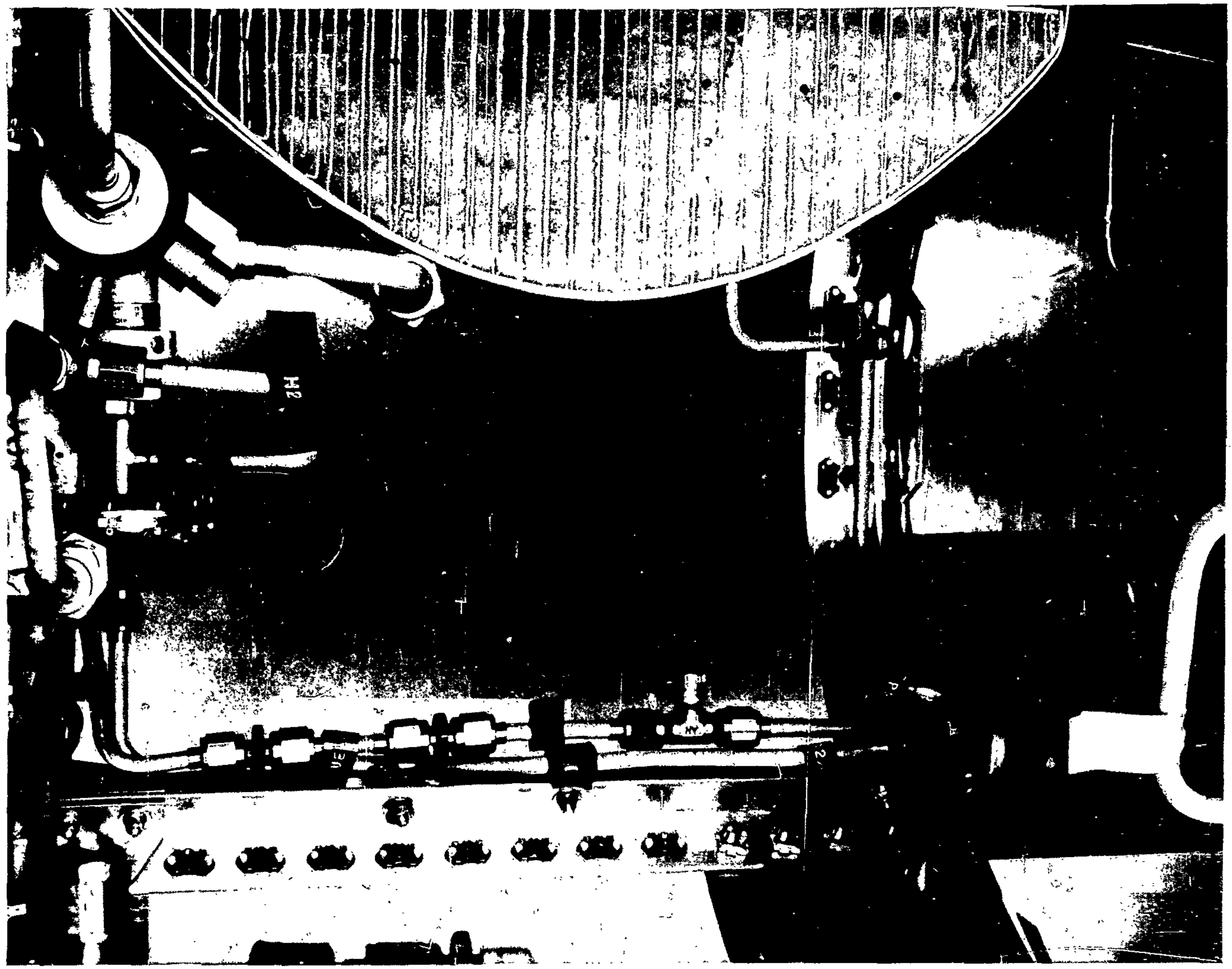


Figure 3-12. Experiment Compartment

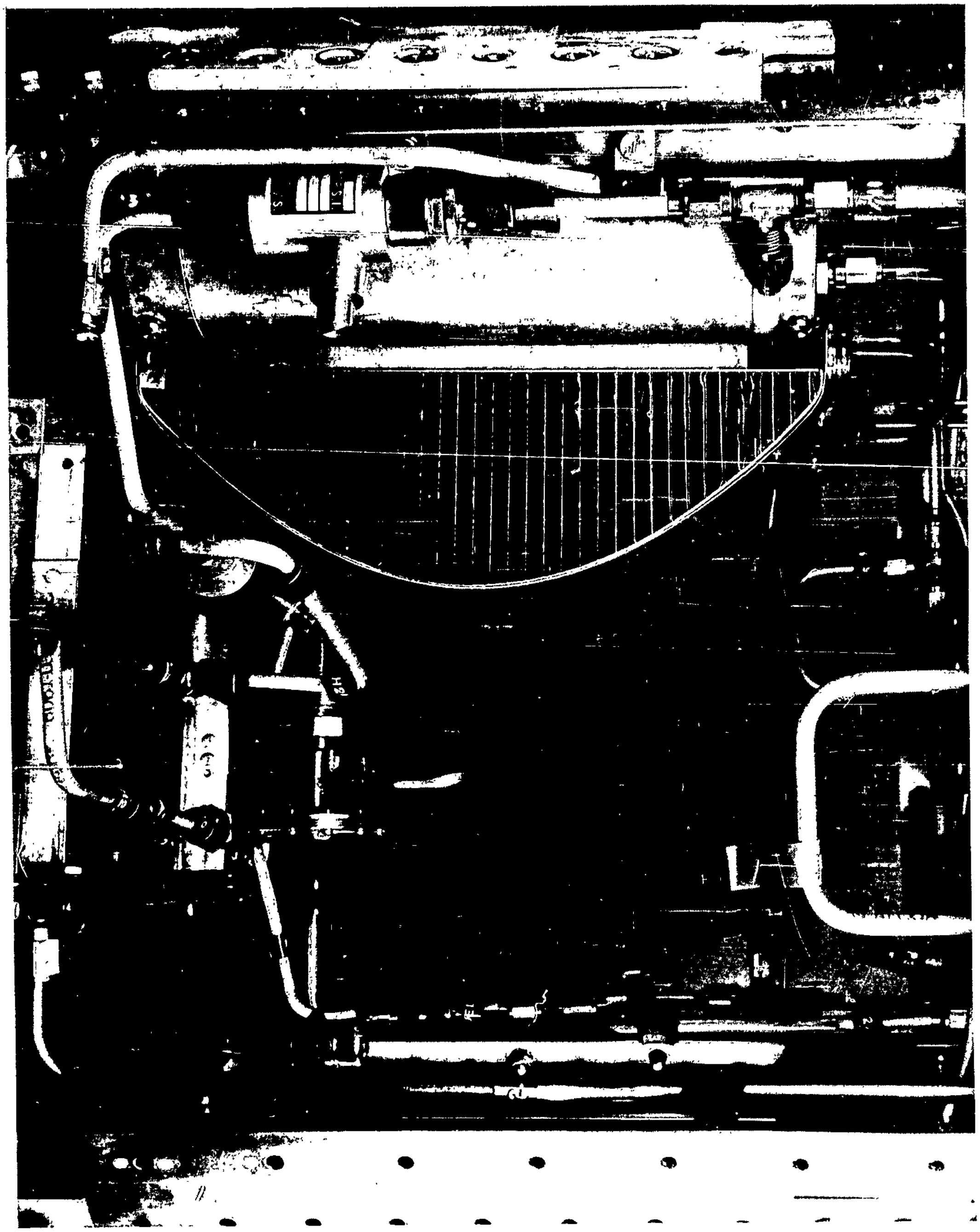


Figure 3-13. Experiment Compartment

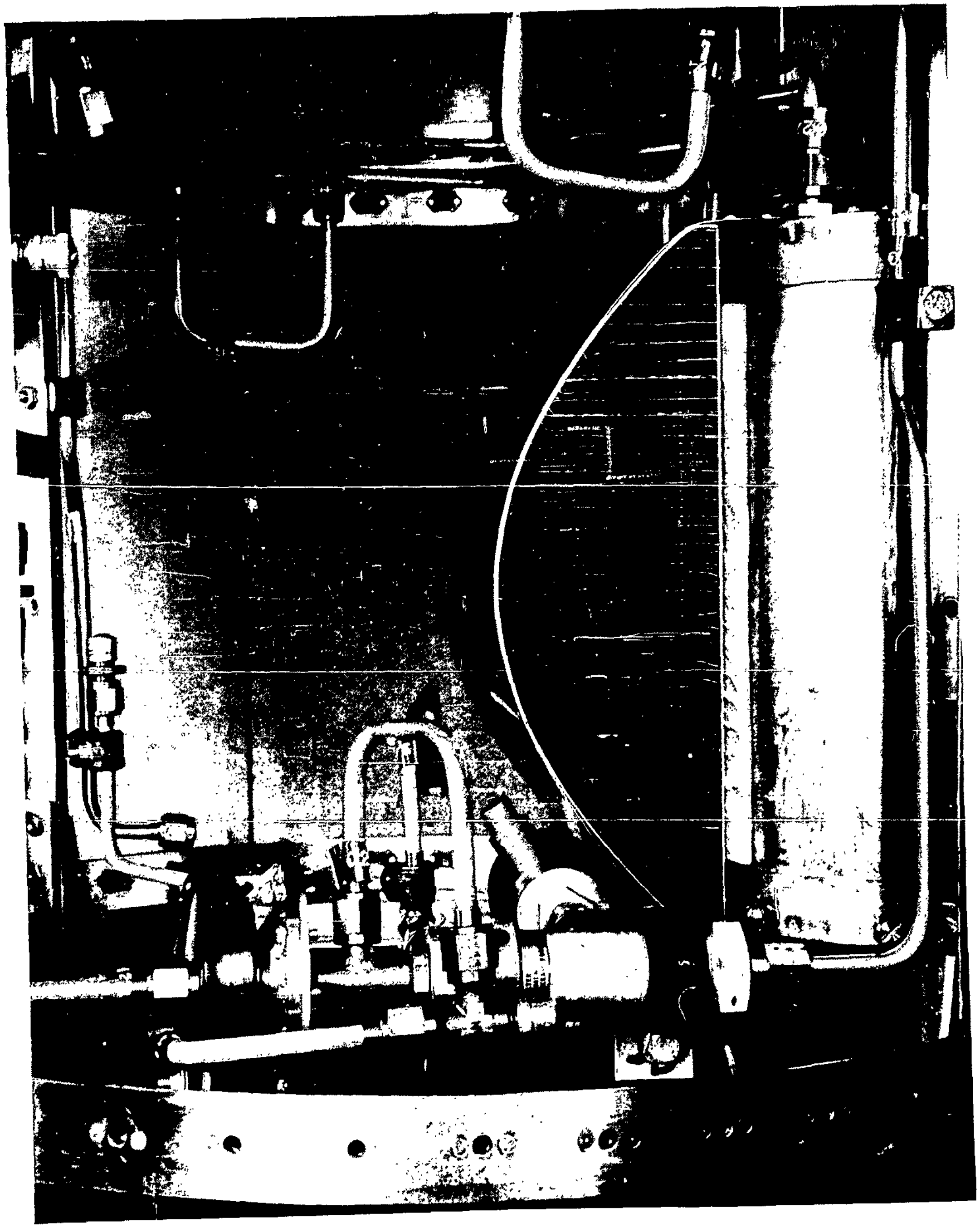


Figure 3-14. Experiment Compartment

- Outlet tubes from each of the oxygen fuel control valves to the pressure transducers, water tank and fuel modules, including the nitrogen connection fittings.

- Inlet and outlet tubes for one of the oxygen purge valves.

3.3.2 Areas of Concern that Arose During Buildup of the Fuel Supply Subsystem

- Vibration considerations indicated that the components should be mounted in the spacecraft with specific orientations. A less desirable orientation of the two oxygen fuel control valves and the two normally open hydrogen purge valves resulted during the drawing layout phase when it became very difficult to find sufficient space on the structure to achieve the desired mounting.

  A re-evaluation of the orientation of these components was made. This resulted in relocating the fuel control valves to the upper end of the Experiment Compartment which required the addition of two mounting struts to the Compartment. Based on the design of the purge valves, it appeared that there should be little cause for concern; however, it was found that these valves could be attached directly to the outlets of the hydrogen fuel control valves by using a bulkhead-type inlet fitting on the purge control valve and that if the opportunity presented itself this change would be made.

- The configuration of the inlet tubes to the filters was changed from that shown on the original layout to acquire more clearance between the tubes and the structure.

- The all-metal clamp originally specified for mounting the pressure regulator was replaced by a rubberized clamp.

- Due to the thin wall tubing being used and the need to connect and disconnect the tubing several times prior to final assembly, it appeared very likely that a leakage problem would be encountered at the flareless fitting on the filter inlet.

  Corrective Action: Made an adapter (Appendix 3A Figure 3A-9 for the oxygen side. It was planned that the P2 filter (with flared fitting) would be used on the hydrogen side. For the flight hardware, both filters would have flared fittings, thus eliminating the need for the adapter.

- The low pressure transducer mounting brackets did not contain holes for the transducer anti-rotation pins.

  Corrective Action: Drilled holes in the brackets. Made plans to modify the MSD drawing to show the pin.

- The configuration of the tubes in the region of the mounting bolts for the transducer mounting brackets was changed from that shown on the original layout to avoid interference with the bolts. In addition, washers were added under the clamps used in supporting the purge tubes to acquire more clearance between the tubes and the bolts.

- The tubes on one side of the Compartment were modified from the layout in the region of the fuel cell module electrical connector to provide sufficient clearance for the mating electrical connector.

3.3.3 Additional Work Required

The following is the work that had been planned to the point of having the Compartment ready for mating to the remainder of the spacecraft:

- Passivate the steel tubing and fittings.

- Clean all the tubing, fittings, orifices, quick disconnect caps and tanks.

- Receive the pneumatic components and conduct appropriate functional tests.

- Make final assembly of the fuel supply subsystem into the Compartment in the clean room.

- Perform functional and leakage tests on the Compartment in the Pneumatics Laboratory.

- Install one fuel cell module and conduct purging tests to finalize the size of the purge orifices.

- Install the second fuel cell module and the appropriate purge orifices and conduct functional and leak checks.

SECTION 4

THERMAL SUBSYSTEM

B. Zeldin

4.0 THERMAL SUBSYSTEM

4.1 THERMAL ANALYSIS

4.1.1 Orbital Heat Flux Analysis

The analysis of the orbital heat fluxes, namely earth emission, solar radiation, and earth albedo, was necessary in order to establish an overall heat balance of the HOPE vehicle and thus to determine the resultant temperature distribution. The magnitude and distribution of the flux is dependent upon the orbit, stabilization, and even the date and time of orbit injection. The fact that HOPE is unstabilized made a precise analysis unfeasible, however, the maximum and minimum heat fluxes were established. The analysis was based upon an orbit with the following characteristics:

Perigee	320 n. miles
Apogee	1145 n. miles
Inclination	30^{o} to equator
Time of Launch	Mid-morning (summer)
Eccentricity	0.099

4.1.2 Vehicle Heat Balance

An overall heat balance, based on the results of the orbital heat flux analysis, internally generated heat and its distribution, was completed. The results of this analysis provided the information necessary to choose the characteristics of the insulation required and the coatings necessary for thermal control.

4.1.3 Fuel Cell Module Heating During Lift-Off

An analysis was performed to predict the temperature rise in the fuel cell modules during the ascent into orbit. The analysis showed that the temperature rise would be less than $5^{o}F$. Consequently, no special provisions for cooling the modules are needed.

4.2 THERMAL DESIGN

4.2.1 Insulation Design

The basic insulation concept was to provide an adiabatic surface which would cover all of the external surface with the exceptions of the radiator surfaces and the Despin Compartment. The function of the insulation was to damp-out temperature transients due to the changes in external flux with time. With this basic concept in mind and with the choice of insulation and coating to be used, the designer was able to design an insulation assembly. The insulation to be used was a 1/2" blanket of embossed 1/4 mil. aluminized mylar (aluminized one side).

4.2.2 Coating Requirements Electrical Compartment

A high emissivity coating (Vita-Var PV 100) was specified for application to the internal surfaces of the Electrical Compartment to help reduce the temperature differences between the electronics packages and their heat sinks.

A high emissivity, low absorptivity coating was to be used for the radiator surfaces. Among the coatings considered was Vita Var PV100 ($\alpha \approx 0.24$ $\epsilon \approx 0.9$). Several others showed even more promise, but were not yet fully tested.

The outside surface of the insulation assembly was to be coated with Vita Var PV100 in order to protect it from overheating and also to render the insulation more efficient by minimizing the difference in temperature between its inside and outside surfaces.

4.2.3 Thermal Grease

A high vacuum, radiation resistant, silicone grease was specified for use at certain metal to metal interfaces to minimize the resistance to heat flow where this was necessary.

4.2.4 Electrical Compartment Radiators

Two diametrically opposite sections of the outside surface area of the Electrical Compartment were left uninsulated. These were to be the radiators for the Electrical Compartment. Thermal paths in addition to the ones already existing were to be provided to carry the heat from the electronics packages and other heat dissipators in the Compartment to the radiators. To minimize temperature gradients within the radiators, doublers were to be provided.

SECTION 5

STRUCTURAL SUBSYSTEM

W. Benton

5.0 STRUCTURAL SUBSYSTEM

Structural subsystem activity covered the following general fields: Vehicle structural hardware procurement, thermal design, pneumatics system design and installation in Development Test Vehicle, investigation of titanium-oxygen compatibility, payload-booster interface coordination with booster manufacturer, and test fixture design for the thermal/vacuum, vibration and shock tests.

5.1 STRUCTURAL HARDWARE PROCUREMENT

5.1.1 Radiators

Procurement and acceptance testing of six radiator castings were completed by the end of September. All parts checked were accepted by Engineering as being satisfactory for use.

Two tools were ordered to facilitate the close machining required for adequate radiator performance as a heat dissipator. The milling/inspection tool was completed and first machining operations were completed on all castings (See Figure 5-1). A lathe tool for turning the radiator curved surfaces was approximately 75% completed.

5.1.2 Despin Compartment

As an advance step to actual fabrication of the Despin Compartment, the drawing was modified to incorporate a shear lip as recommended by the booster manufacturer. At this same time the hole pattern to match the booster/payload interface was added to the drawing as shown on Figure 5-2 . Manufacturing planning was completed on the Despin Compartment structure.

5.1.3 Lifting Sling Attach Points

One piece of design work not completed in Phase I was the definition of the lifting sling attach points on the forward portion of spacecraft. These points were established in Phase Ia and the necessary mating design incorporated on both lifting sling and insulation drawings.

5.2 THERMAL DESIGN

5.2.1 Insulation Design

During Phase Ia, the insulation design was completed and ready for release. Manufacturing, planning and producibility personnel were reviewing the design from their respective viewpoints.

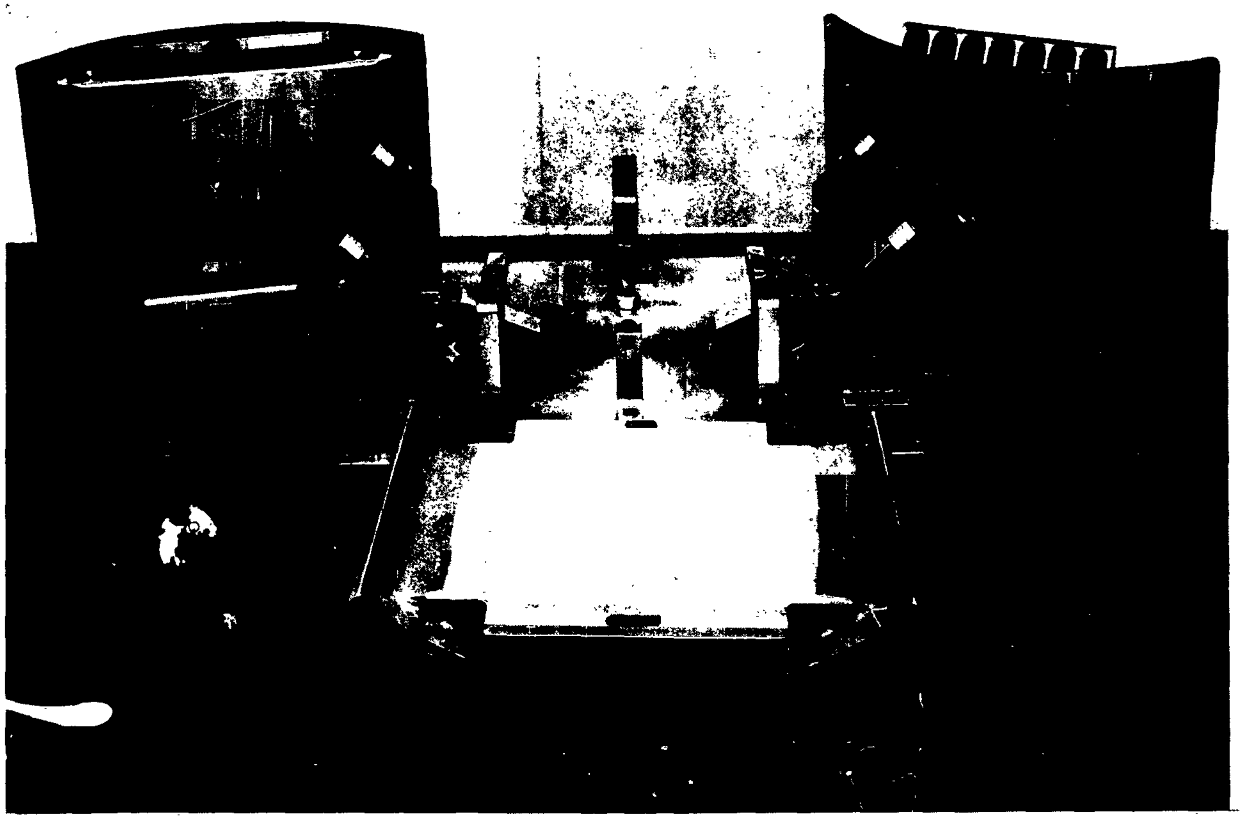
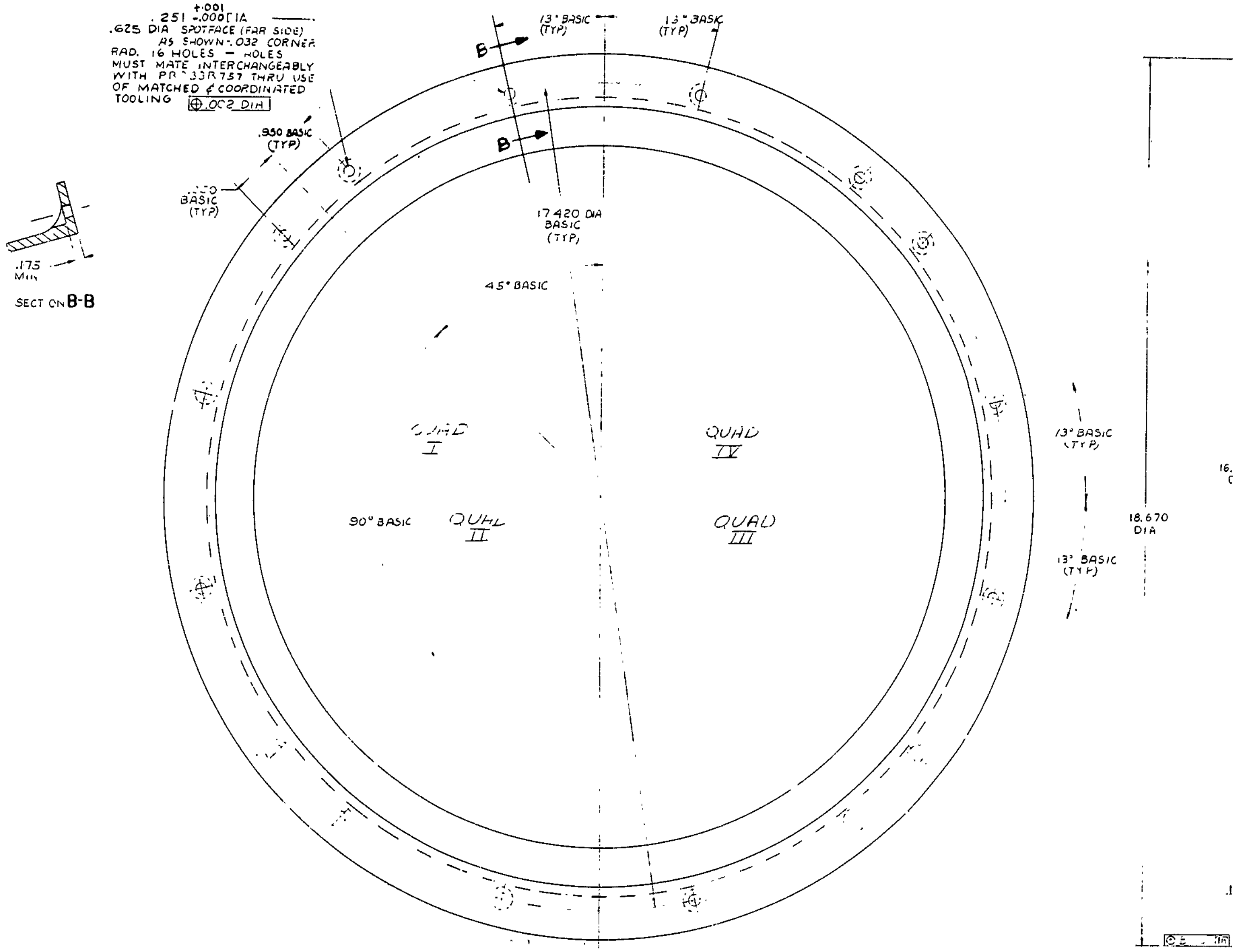
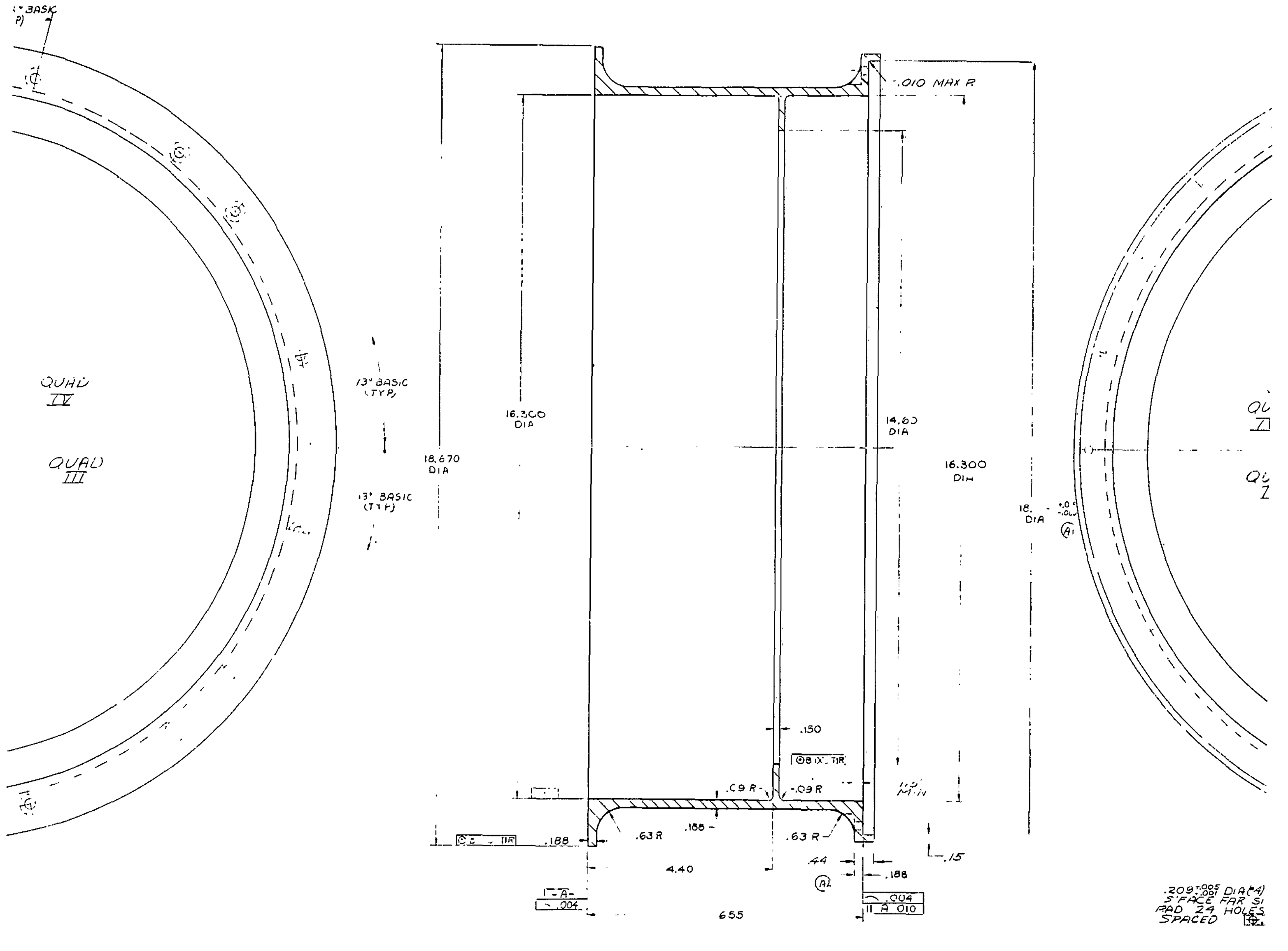


Figure 5-1. Milling/Inspection Tool to Facilitate Close Machining of Castings



.251 +.001 -.000 DIA
.625 DIA SPOTFACE (FAR SIDE) AS SHOWN-.032 CORNER RAD. 16 HOLES — HOLES MUST MATE INTERCHANGEABLY WITH PR 33R757 THRU USE OF MATCHED & COORDINATED TOOLING
.950 BASIC (TYP)
BASIC (TYP)
.175 MIN
SECT ON B-B
13° BASIC (TYP)
13° BASIC (TYP)
17.420 DIA BASIC (TYP)
45° BASIC
QUAD I
QUAD IV
90° BASIC
QUAD II
QUAD III
13° BASIC (TYP)
13° BASIC (TYP)
18.670 DIA

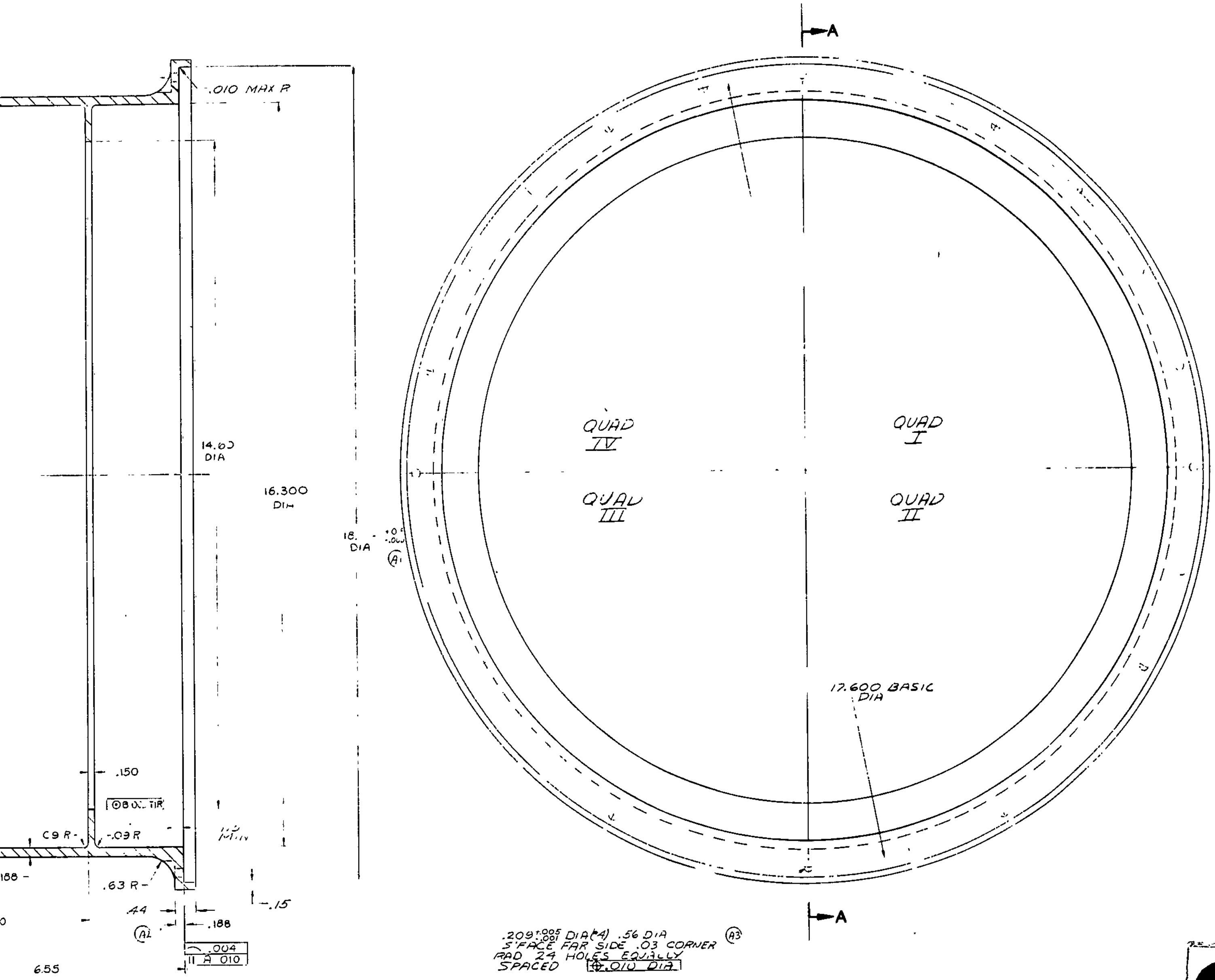
1



SECTION A-A

(P1)

2



3

GENERAL NOTES

1. DWG TERMS & TOLERANCES PER GE SPEC 118A1664
2. MARK "GE PR238R761P1" PER GE SPEC 118A1526 CL II (ELEVEN)
3. MAX MACHINED SURFACE ROUGHNESS 125 UNLESS OTHERWISE SPECIFIED
4. [illegible] 20 PER MIL-C-5541
5. FLUORESCENT PENETRANT INSPECT PER GE SPEC 118A1547 CLASS I (ONE) PARTS (MACHINED FORGING)

Figure 5-2. De-Spin Adapter

The insulation configuration is shown in Figure 5-3 . It consists of four, semi-rigid panels curved to match the spacecraft structure. Each individual panel consists of inner and outer shells formed from glass cloth preimpregnated with an epoxy resin. This material is formed to a shape matching the contour of the spacecraft and cured under heat and pressure. These shells are provided with U-shaped edges to contain layers of aluminum coated mylar film. The two shells are then joined by teflon screws and nuts. Spacers of this same material prevent compacting of the superinsulation and resultant degradation of its thermal characteristics.

Each pair of insulation panels is mated on the spacecraft by hook-and-pile re-straining straps. This system was selected because of its ease of manipulation and wide range of adjustment in tension.

For a structural tie directly to the spacecraft, a minimum number of steel bolts are used. This minimizes the direct heat paths through the insulation consistent with the required tie-down strength to resist spinup, despin and launch loads.

Cutouts are provided in the insulation envelope to expose the fuel cell radiators and to provide additional radiating surfaces in the area of the Electrical Com-partment. One of these cutouts was to be used for mounting the electrical umbilicals required for prelaunch monitoring of the payload experiment. Two additional cutouts in the area of the Experiment Compartment were to permit access to the fuel charging disconnects on the spacecraft. These two areas were to be isolated from the remainder of the volume inside the booster shield by a rubber bellows to prevent fuel gases vented from the fuel cell before launch from collecting and forming a potentially explosive mixture. The locations of these cutouts were communicated to the booster manufacturer so that matching cutouts and cover doors would be provided in the heat shield.

An external coating would be applied to the insulation assembly to assist in the thermal control of the spacecraft.

5.2.2 Thermal Design in Electrical Compartment

Thermal control of the Electrical Compartment became an important item for design consideration during the Phase Ia portion of the Fuel Cell development program. For adequate cooling of the electronic components within the compart-ment, several design changes were planned:

- All component packages would be designed with flat bases so the cases would come into intimate contact with the bulkheads over a maximum area for best possible heat transfer.

- To make heat transfer through the bases of the component cases even more efficient, silicone grease was to have been spread between all such mating surfaces. This compound eliminates air pockets, assuring intimate contact.

- The two cutouts in the spacecraft insulation, discussed in paragraph 5.2.1 above, were provided to expose the Electrical Compartment access doors. These doors then were to act as radiators to dissipate waste heat from the components in the Compartment. To aid heat flow to the doors, thermal transfer straps of thin aluminum strip were to be provided direct from the hot portions of the cases to the doors. Silicone grease was to be spread between the electrical umbilical support brackets and the bulkhead and between the brackets and the door. The brackets were to be located so that the installation of the door would force the door and bracket tight together.

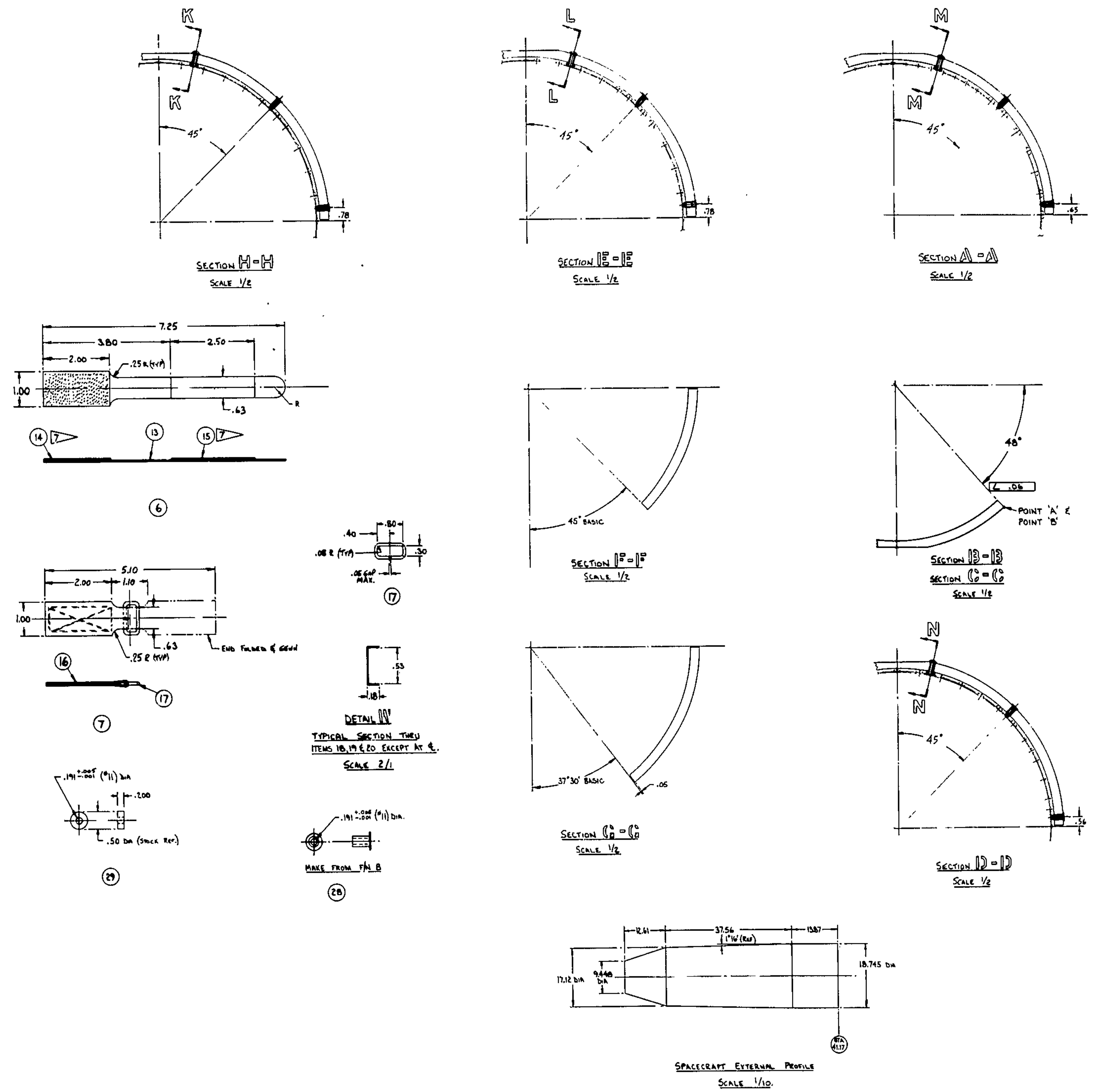
  This arrangement would turn the brackets into efficient heat transfer straps from the bulkheads to the access door/radiators. Silicone grease was also to be spread between all mating surfaces of access doors and spacecraft support structure, again to promote heat transfer to the access door/radiators.

- Silicone grease was to have been added between mating surfaces of the Electrical and Experiment Compartments.

- A special coating was to have been sprayed over the surfaces of the electronic components and Compartment interior. This coating was to have had a high thermal emissivity to promote heat transfer from components to walls.

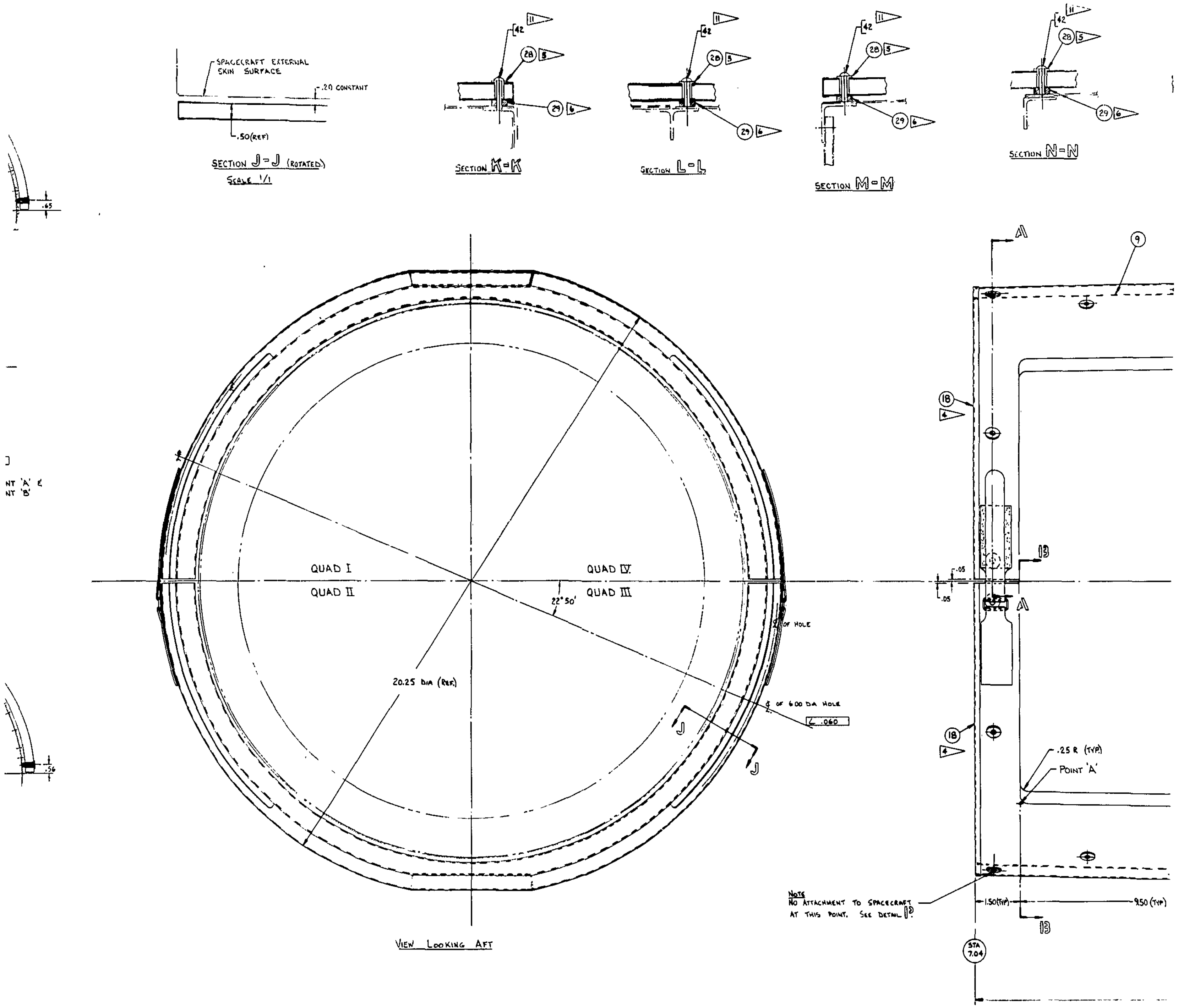
5.3 PNEUMATICS SYSTEM DESIGN

Completion of the pneumatics installation design was accomplished during this reporting period. The layout drawing is reproduced as Figures 3-2a, b and c and 301a, b and c. This preliminary drawing would be converted to a finished installation drawing suitable for formal release after the DTV installation is complete. During this DTV installation, all design discrepancies would be noted and corrected on the final drawing before release.



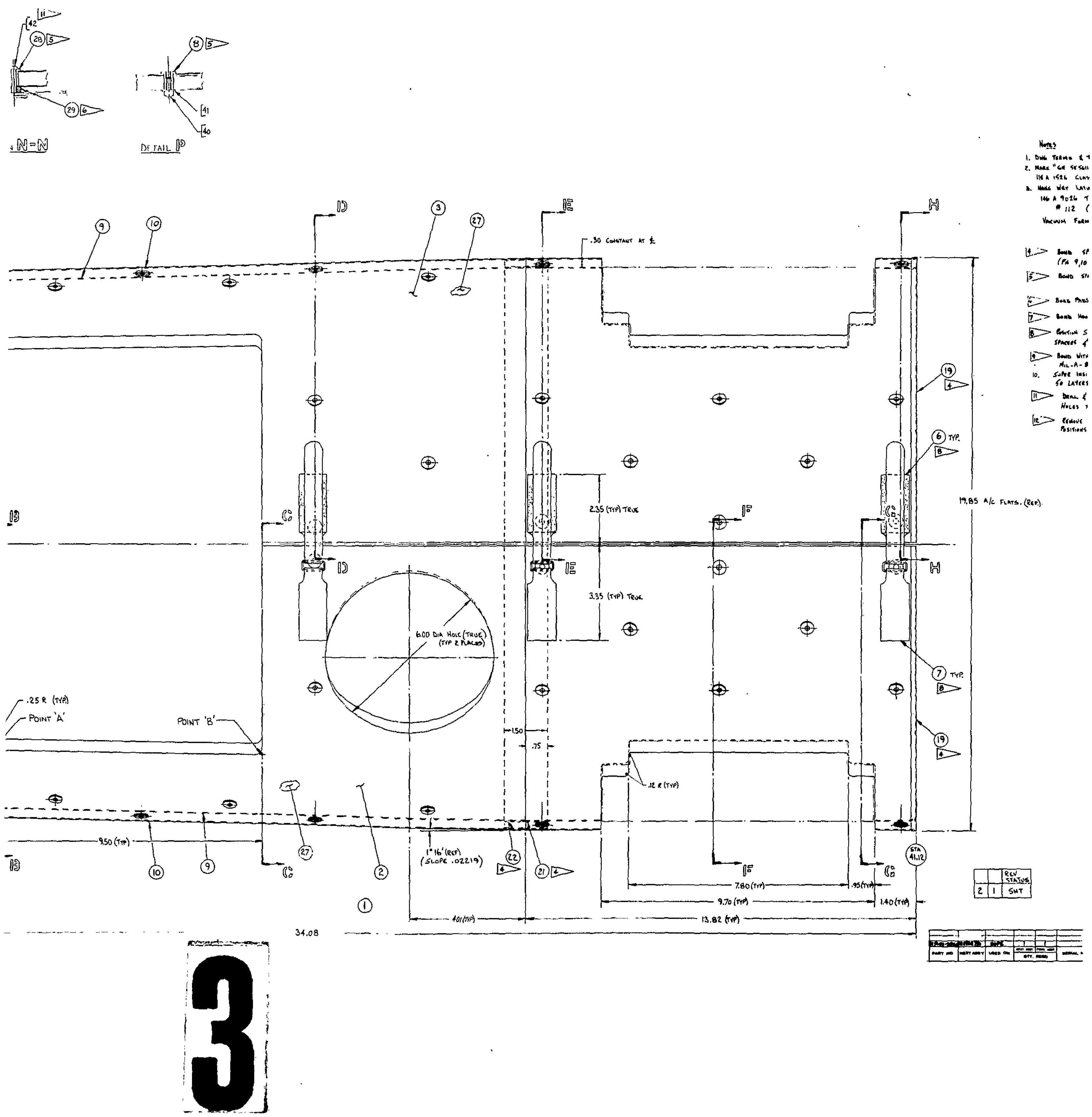
SECTION H-H
SCALE 1/2
SECTION E-E
SCALE 1/2
SECTION A-A
SCALE 1/2
7.25
3.80
2.00
2.50
.25 R (TYP)
1.00
.63
6
5.10
2.00
1.10
1.00
.63
.25 R (TYP)
END FOLDED & SEWN
7
.40
.80
.08 R (TYP)
.30
.06 GAP MAX.
17
.53
.18
DETAIL W
TYPICAL SECTION THRU ITEMS 18, 19 & 20 EXCEPT AT ℄.
SCALE 2/1
.200
.50 DIA (STOCK REF.)
29
MAKE FROM F/N 8
28
45° BASIC
SECTION F-F
SCALE 1/2
48°
POINT 'A' & POINT 'B'
SECTION B-B
SECTION C-C
SCALE 1/2
37°30' BASIC
.05
SECTION C-C
SCALE 1/2
45°
.56
SECTION D-D
SCALE 1/2
12.61
37.56
13.87
1°16' (REF)
17.12 DIA
9.448 DIA
18.745 DIA
SPACECRAFT EXTERNAL PROFILE
SCALE 1/10.

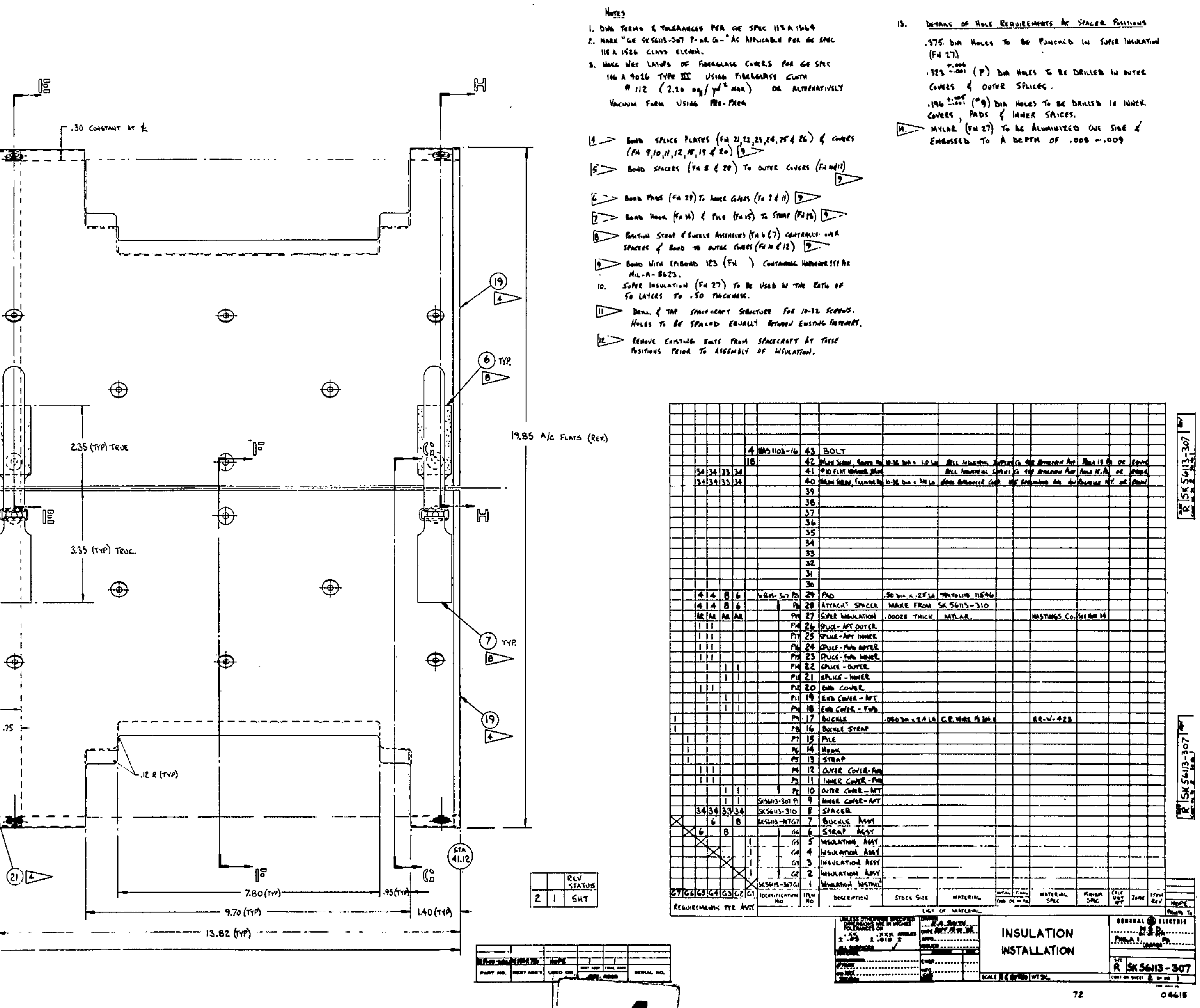
1



SPACECRAFT EXTERNAL SKIN SURFACE
.20 CONSTANT
.50(REF)
SECTION J-J (ROTATED)
SCALE 1/1
SECTION K-K
SECTION L-L
SECTION M-M
SECTION N-N
42
28
29
11
5
6
QUAD I
QUAD II
QUAD IV
QUAD III
22°50'
20.25 DIA (REF)
℄ OF HOLE
℄ OF .600 DIA HOLE
.060
J
A
B
9
18
4
.05
.25 R (TYP)
POINT 'A'
NOTE
NO ATTACHMENT TO SPACECRAFT AT THIS POINT. SEE DETAIL B
1.50(TYP)
9.50 (TYP)
STA 7.04
.65
.56
VIEW LOOKING AFT

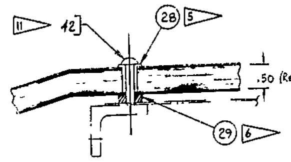
2


DETAIL D
.30 CONSTANT AT ℄
2.35 (TYP) TRUE
3.35 (TYP) TRUE
6.00 DIA HOLE (TRUE) (TYP 2 PLACES)
19.85 A/C FLATS (REF)
.25 R (TYP)
POINT 'A'
POINT 'B'
1.50
.75
.12 R (TYP)
9.50 (TYP)
1° 16' (REF) (SLOPE .02219)
STA 41.12
7.80 (TYP)
.95 (TYP)
9.70 (TYP)
1.40 (TYP)
4.01 (TYP)
13.82 (TYP)
34.08
REV STATUS
2 1 SHT
NOTES
PART NO
NEXT ASSY
USED ON
QTY. REQD
3

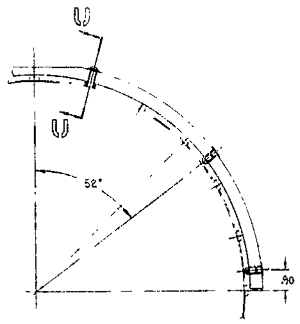


4

Figure 5-3. Insulation Installation

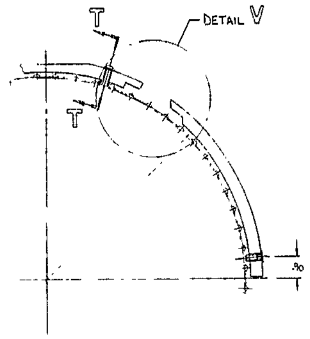


SECTION T - T



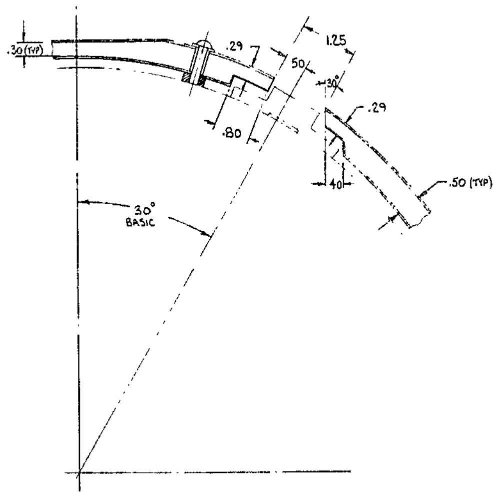
SECTION S - S

SCALE 1/2



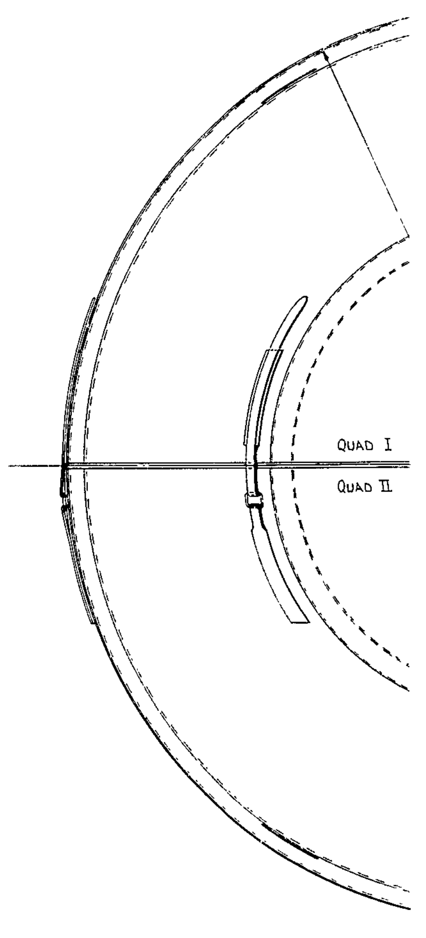
SECTION R - R

SCALE 1/2

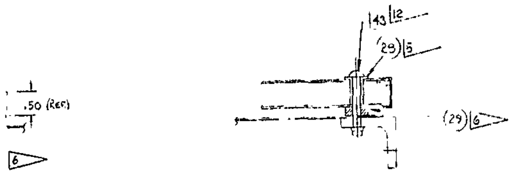


DETAIL V

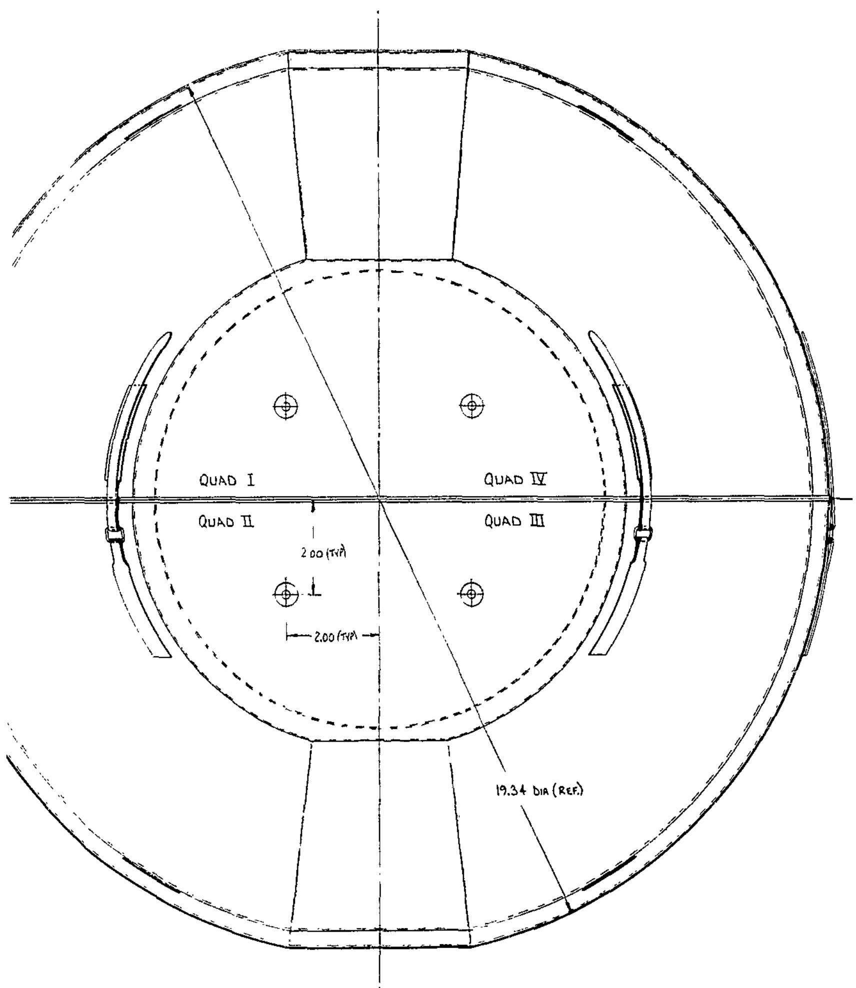
(TYPICAL 4 PLACES)



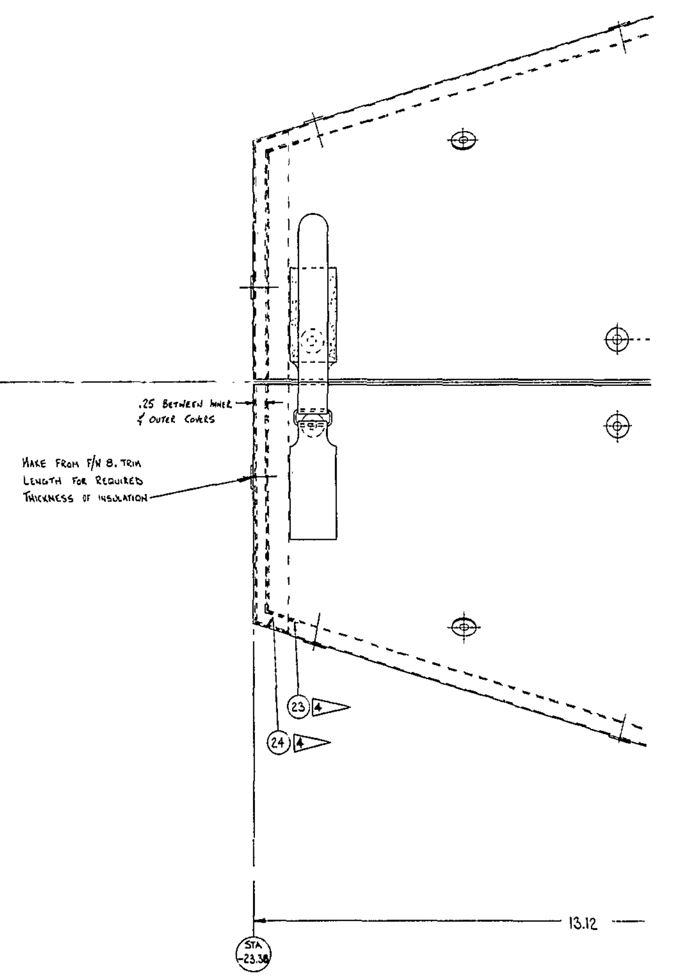
1



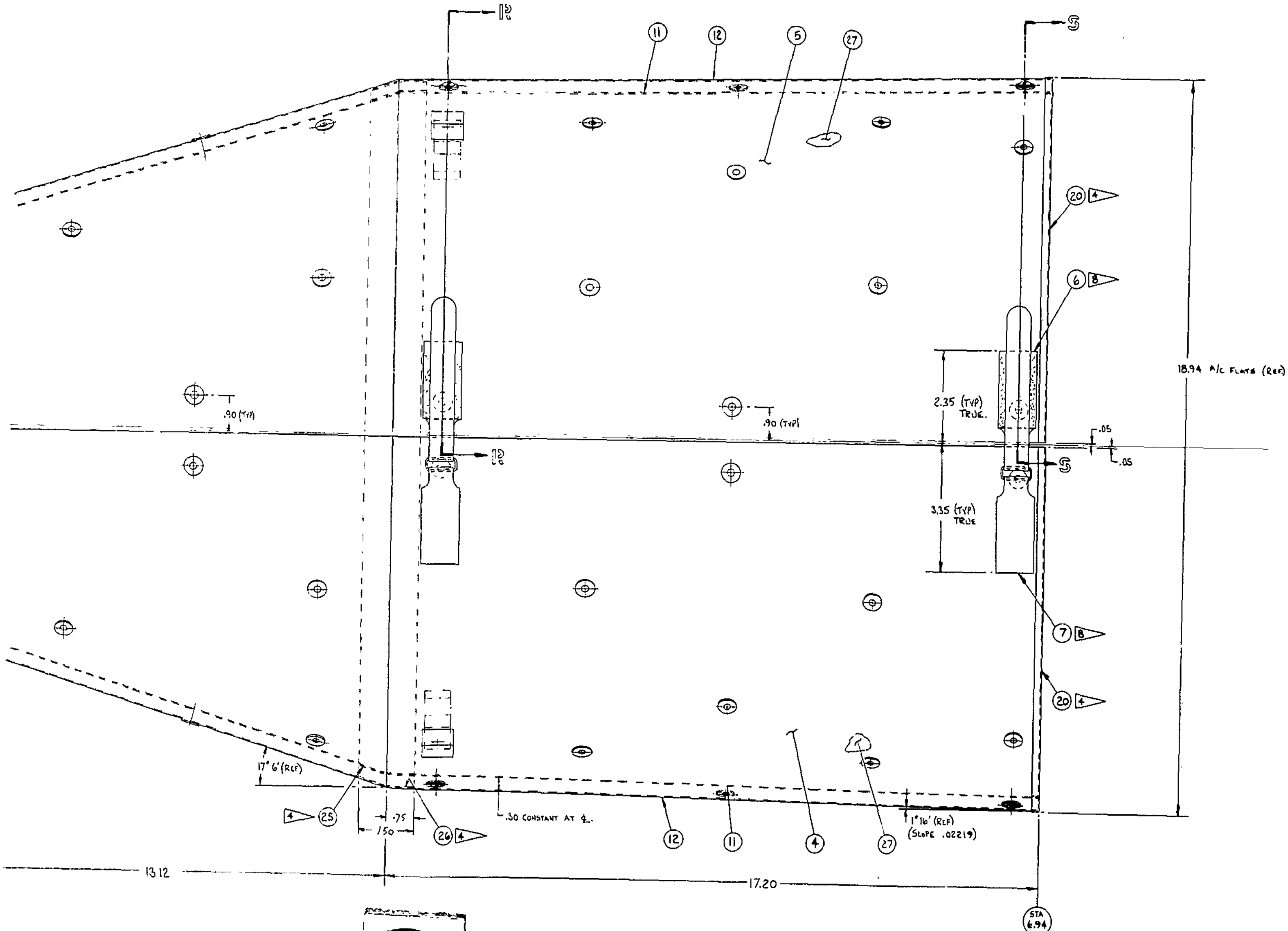
SECTION U-U



VIEW LOOKING AFT



2



5-9/5-10

Figure 5-3. Insulation Installation (Cont'd)

Composition and function of the pneumatics installation is covered in detail in Section 3 of this report, the discussion here will concern itself only with structural effects of the installation.

Several pieces of bracketry were installed to support pneumatic system components. Installation of these parts required drilling the spacecraft structural members to provide bolt and rivet holes. To these brackets were bolted cushioned and plain clamps for restraint and/or support of components and fuel lines.

Component locations within the Experiment Compartment were determined by such considerations as permissible "g" levels, space limitations and most efficient tube routing for minimum total weight. Some components are not only sensitive to environmental "g" levels, but also must be oriented in a certain way for most reliable operation. For a maximum of access area to the spacecraft and a maximum of working space within for checkout and adjustment, tubing and components were located close to the structural members as much as possible without causing interference with the structure or other internal equipment.

5.4 ELECTRICAL COMPARTMENT DESIGN DEVELOPMENT

Original plans for the interface between the Electrical Compartment structure and the equipment mounted on that structure called for installation of inserts in the Compartment's sandwich bulkheads. These inserts would be arranged to match the tie-down provisions on the electronic equipment to be mounted. Figure 5-4 shows the layout drawing used to locate the inserts in the sandwich bulkheads. Once these inserts are installed in the bulkheads, that configuration is "frozen" as the inserts cannot be readily moved from place to place.

Plans for the structural testing of the DTV included the installation of mockups of any electronic components not available at the time of test. These would simulate the dynamic loading on the bulkheads and serve to test out the structural supports for the design loading.

Locations for the electrical umbilical disconnects in the Electrical Compartment walls were chosen. These were to have been mounted in the area of a cutout in the Compartment access door on the tower side of the spacecraft. Brackets to support these disconnects are shown in Figure 5-4 . An additional function of these brackets with respect to thermal design is discussed in Paragraph 5.2.2 above.

Terminal blocks used to distribute telemetry and data gathering signals are also shown in Figure 5-4 . These are mounted on the Electrical Compartment access door opposite the tower. A total of four blocks, each containing 42 side-feed connector modules, was planned. These would all be readily accessible for

service by merely removing the door, the wire bundles being provided with extra length for this purpose.

5.5 TITANIUM-OXYGEN COMPATIBILITY INVESTIGATION

A question of titanium-oxygen compatibility was raised during the HOPE Phase Ia design period. Investigation showed that a problem may exist in storing oxygen in titanium tanks in that a possible exothermic, pyrophoric reaction might occur between the two materials.

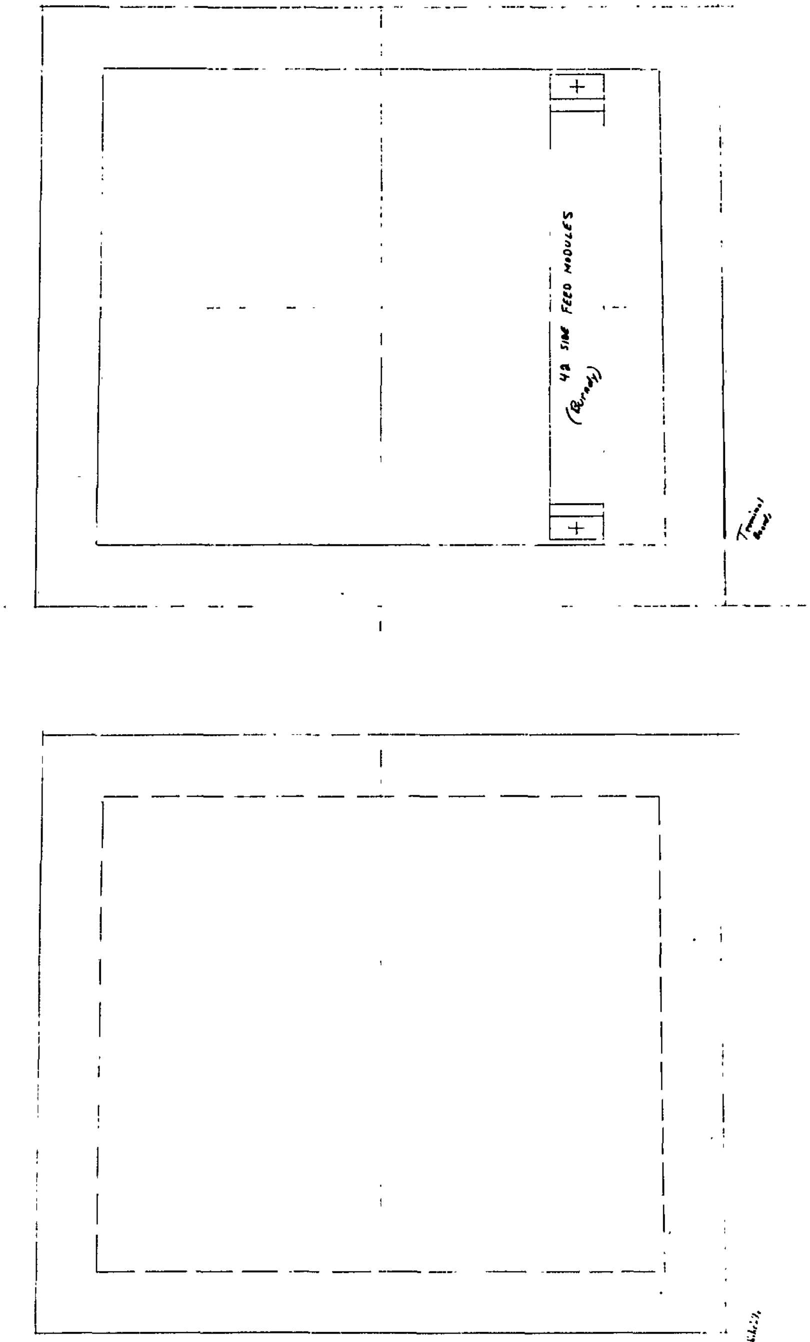
5.5.1 Background

Work done at Battelle Memorial Institute (Reference No. 1) has established the fact that an impact is required to ignite titanium in liquid oxygen (LOX). Merely exposing fresh, unoxidized surfaces to the LOX, as had once been thought sufficient, was shown to be inadequate to cause ignition. Impact energies of 70-ft/lb. were found to cause detonation or ignition in all cases. Lower impact energies gave erratic results, though ignition was obtained down to energies of 10 -ft/lb. In all cases, impact occurred on a surface in direct contact with the LOX.

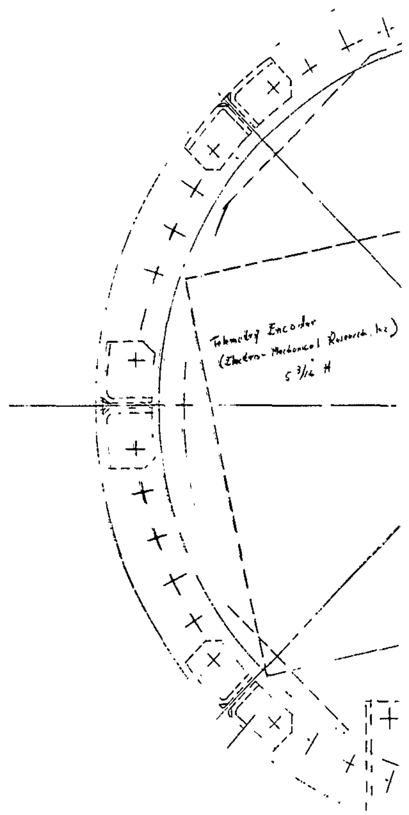
In a gaseous oxygen atmosphere, no impact energy input is necessary to obtain a reaction, exposure of fresh surfaces is enough if the gas pressure is above a certain value. Stanford Research Institute reported a minimum pressure of 350 psi required for a reaction while Battelle reported a minimum of 100 psi for 6Al-4V titanium alloy. Both these series of tests exposed fresh titanium surfaces by breaking a bar in tension in a container pressurized with gaseous oxygen.

A test series by General Dynamics/Astronautics (Reference No. 2) showed that impact-puncture of titanium vessels containing gaseous oxygen caused ignition at approximately atmospheric pressure. The minimum pressure to obtain ignition is lowered because of the energy added to the system at the same time that a fresh surface is created. Using high-velocity particles, it was found that ignition did not occur when the titanium container was not ruptured; fresh surface is a requirement at least at the pressures investigated - 0 to 50 psi.

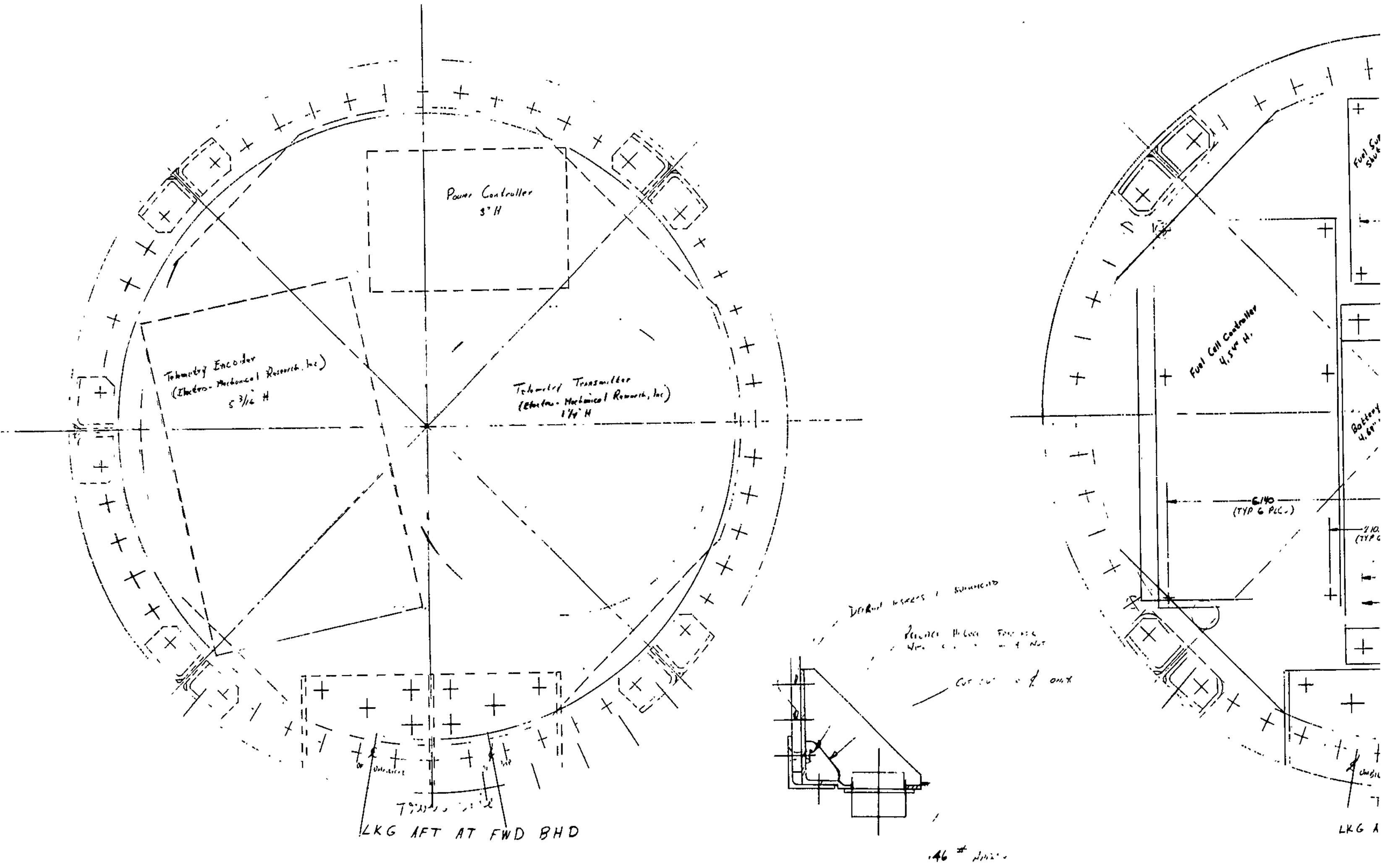
Stanford Research Institute has obtained titanium ignition without the creation of fresh surface or use of impact. A pure titanium test sample with an oxidized surface was sealed in a glass tube which was broken in a chamber filled with oxygen gas under pressure. At pressures of 550 psi and above, ignition took place. In the Stanford testing mentioned above, titanium test specimens were pressurized at a slow rate before breaking to expose fresh surfaces. No ignition took place during the pressurization phase of the testing even though pressures were run as high as 2000 psi. These tests inferred that the sudden exposure to the pressure in the testing under discussion here caused the reaction.



(Developed Sizes of Electrical Compt. Doors)

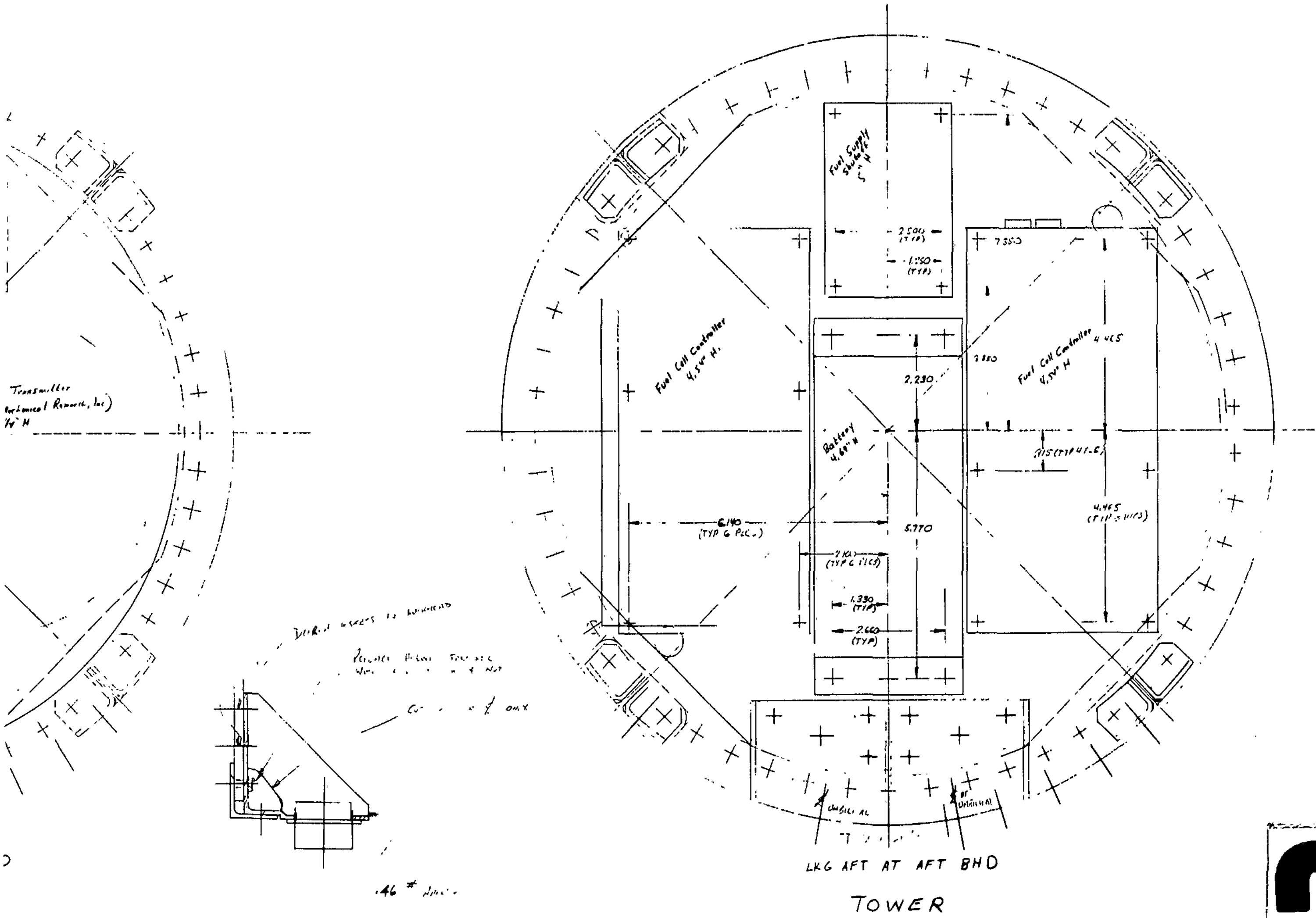


1



2

Figure 5-4. La



3

LAYOUT OF ELECTRICAL COMPONENT
ATTACH. POINTS (HOPE FUEL CELL)
SK 56113-316

Figure 5-4. Layout of Electrical Component Attachment Points (HOPE Fuel Cell)

5.5.2 Line of Investigation

It must be noted that none of the investigations discussed in paragraph 5.5.1 above duplicate HOPE oxygen tank charging or handling techniques. The charging plan for HOPE involved pressurization of the oxygen tank to 2500 psi over a 30-minute period. In addition, the tank is relatively well protected from accidental puncturing when installed in the spacecraft and no oxygen charging was planned unless the tank was installed.

A first step in the attempt to reduce the reaction possibility was an investigation of possible internal coatings for the tank. Several plastic and elastromeric compounds were considered such as Teflon and Kel-F. The coatings approach was dropped, however, when the question of maintaining the coating on the threaded fill ports was encountered. Installation of the fittings would tend to remove any coating, exposing the titanium surfaces to the oxygen gas.

A testing program to evaluate the actual magnitude of the problem for the HOPE conditions was mapped. First, a pair of tanks cleaned for oxygen service were to be pressurized to 3000 psi for a total of 5 cycles each by the ground service unit developed for the HOPE program. A third tank was to have been pressurized to 3000 psi a total of 50 times. This testing would have shown up any tendencies for the HOPE pressurization procedures to develop ignition in the tanks. A 3000 psi pressure was selected as being high enough to force a reaction with any fresh titanium surfaces that might be exposed within the hairline welding cracks around the weld backup ring. These hairline cracks have been shown by previous pressurization and burst testing to neither propogate nor cause a rupture. The oxygen charging would identify any tendency of the gas to react with these cracks on the bottles in question.

If any reaction were encountered during the above described testing, the titanium tanks would be judged unsafe for use and some other tank would be sought. If no reaction were experienced, all remaining tanks on hand would be subjected to a pressurization cycling of 3000 psi ten times each. Any reaction experienced during any testing would rule out the use of 6A1-4V titanium tanks for gaseous oxygen storage on the HOPE spacecraft. In such an event, a new tank or some other tank would have to be sought.

At the same time as the above test program was being prepared, an alternate effort was the canvassing of the pressure vessel industry. Availability of an alternate tank of some other material that would meet HOPE mission requirements with respect to internal volume, allowable weight and compatibility with existing mounting arrangements in spacecraft was investigated.

5.6 TEST FIXTURE DESIGN

Testing of the HOPE Fuel Cell System involved several different test machines and installations. Each type of machine required an adapting fixture to fit the HOPE spacecraft to the test.

5.6.1 Seven-Day Bench Test

No special fixture was required for the 7-day bench test. It was planned to mount the spacecraft in the horizontal position on the ground handling dolly and perform the test. The only test requirement on the spacecraft is that the spacecraft be located such that all parts are readily accessible for possible servicing during the test. Use of the dolly meets this requirement adequately.

5.6.2 Seven-Day Thermal/Vacuum Test

To adequately support the spacecraft for this thermal/vacuum test, it is only necessary to orient the structure such that the fuel cell product water does not have to be transported uphill from the cells. Locating the cells on top and bottom of the spacecraft meets this need as this keeps both the product water lines in a horizontal plane.

From a thermal standpoint, the spacecraft structure must not be allowed to lose heat to the chamber walls by direct conduction. To prevent this, all metal to metal joints were supplied with insulating Teflon bushings and washers.

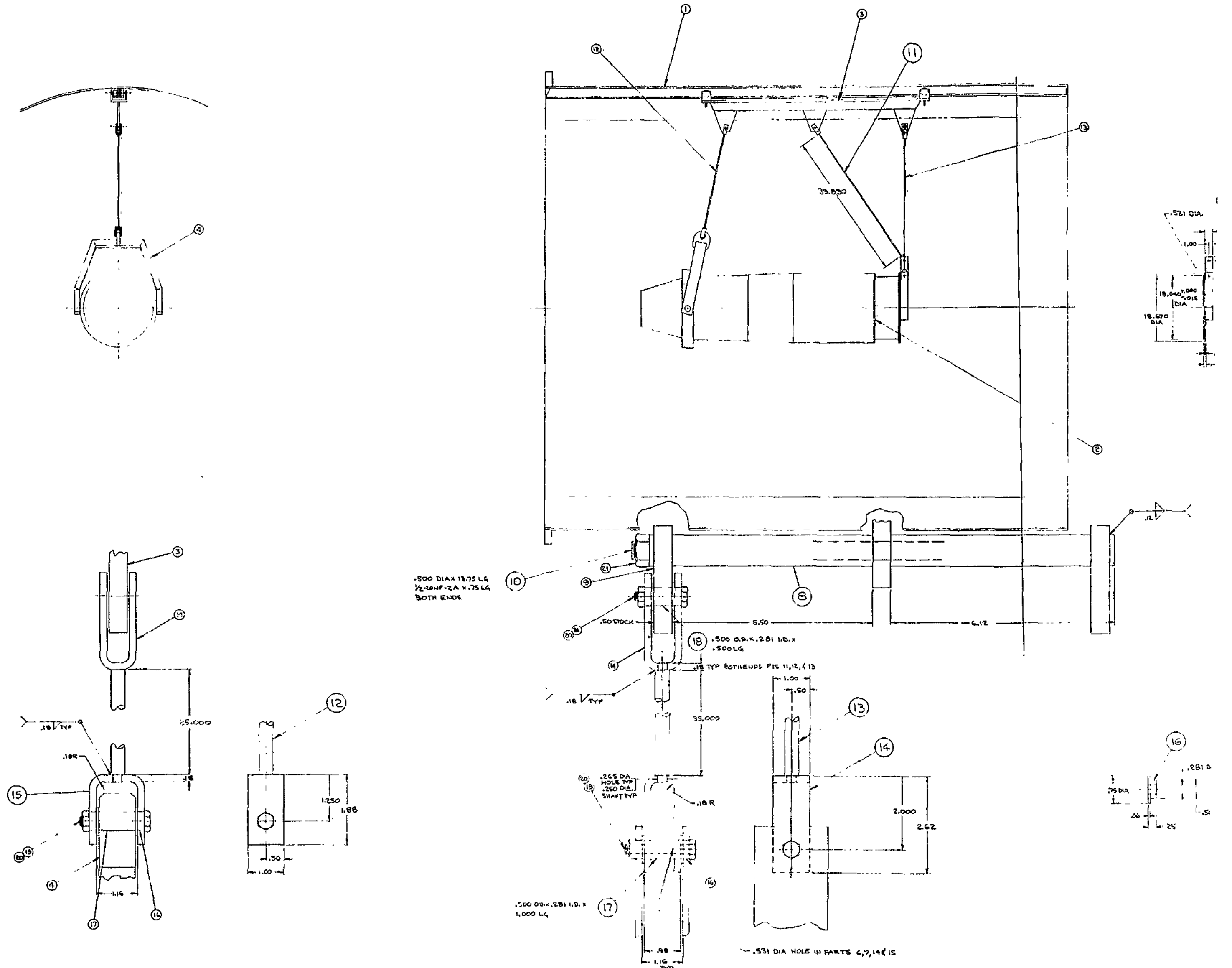
Figure 5-5 shows the vacuum chamber mounting fixture. This drawing is not complete.

5.6.3 Shock and Vibration Tests

For the shock and vibration tests, a fixture was designed as shown in Figure 5-6 that adapted the DTV to both test machines. Structurally, no other provisions had to be made for these tests.

5.6.4 Acceleration Test

GE-MSD has no centrifuge facilities for testing a structure the size of the HOPE spacecraft. As a result, requests for bids were sent to several locations to assess capabilities and costs for conducting the tests felt necessary. No final decision had been made on test location and, therefore, no fixture design had been begun.



.500 DIA x 13.75 LG
1/2-20NF-2A x .75 LG
BOTH ENDS
.50 STOCK
5.50
6.12
.500 O.D. x .281 I.D. x .500 LG
35.000
32.000
1.250
1.88
2.000
2.62
.531 DIA HOLE IN PARTS 6,7,14 & 15

1

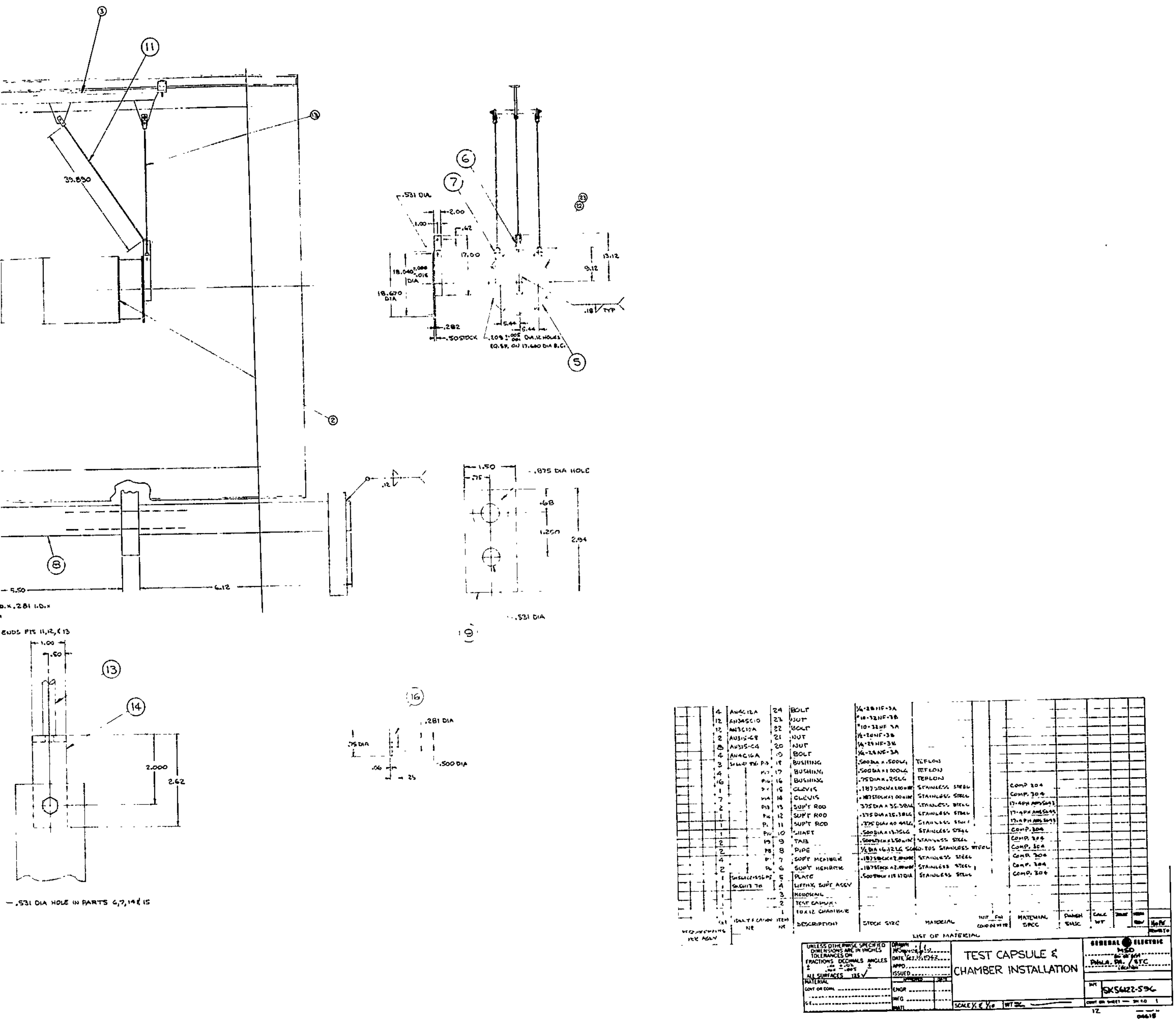
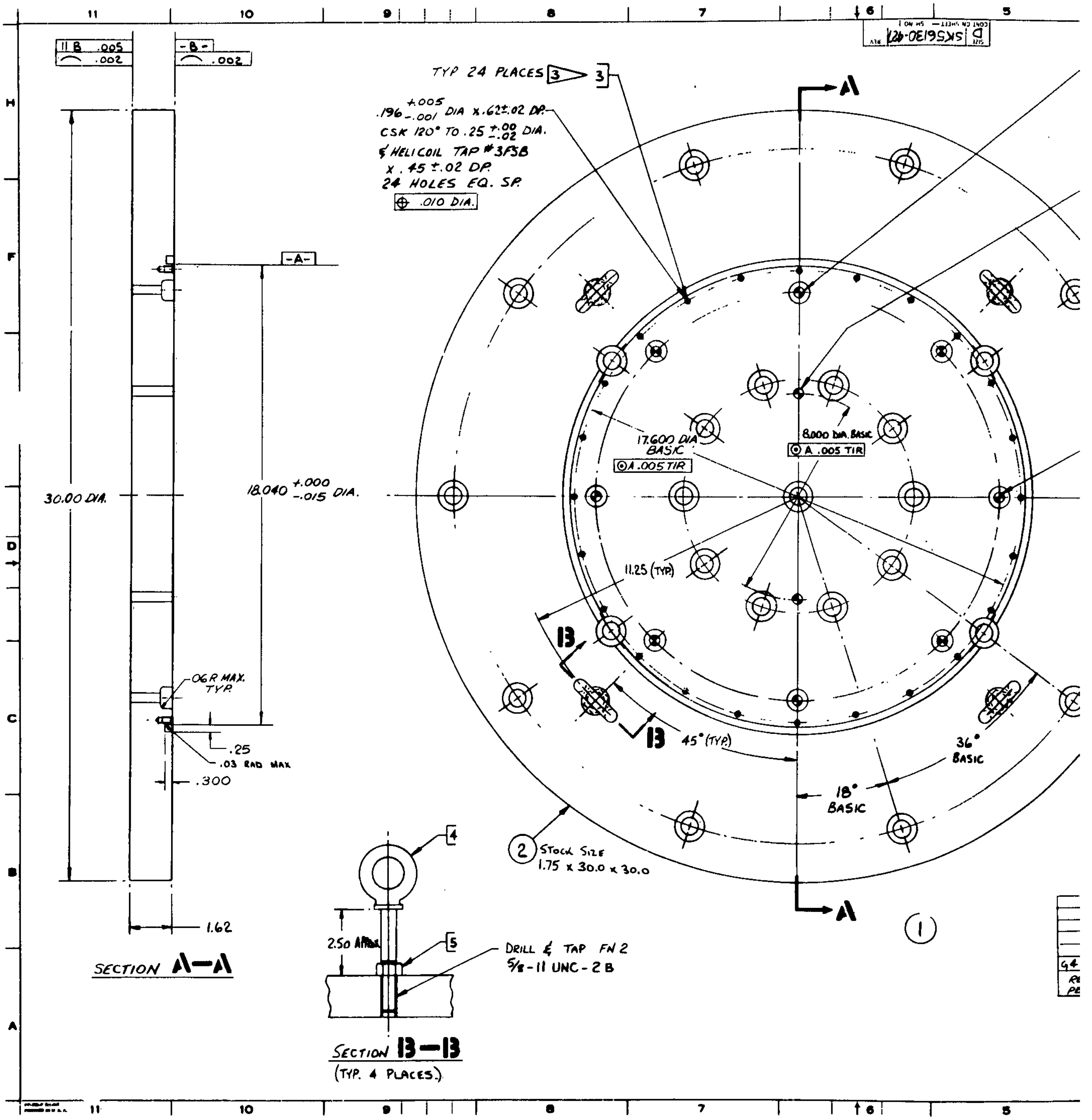
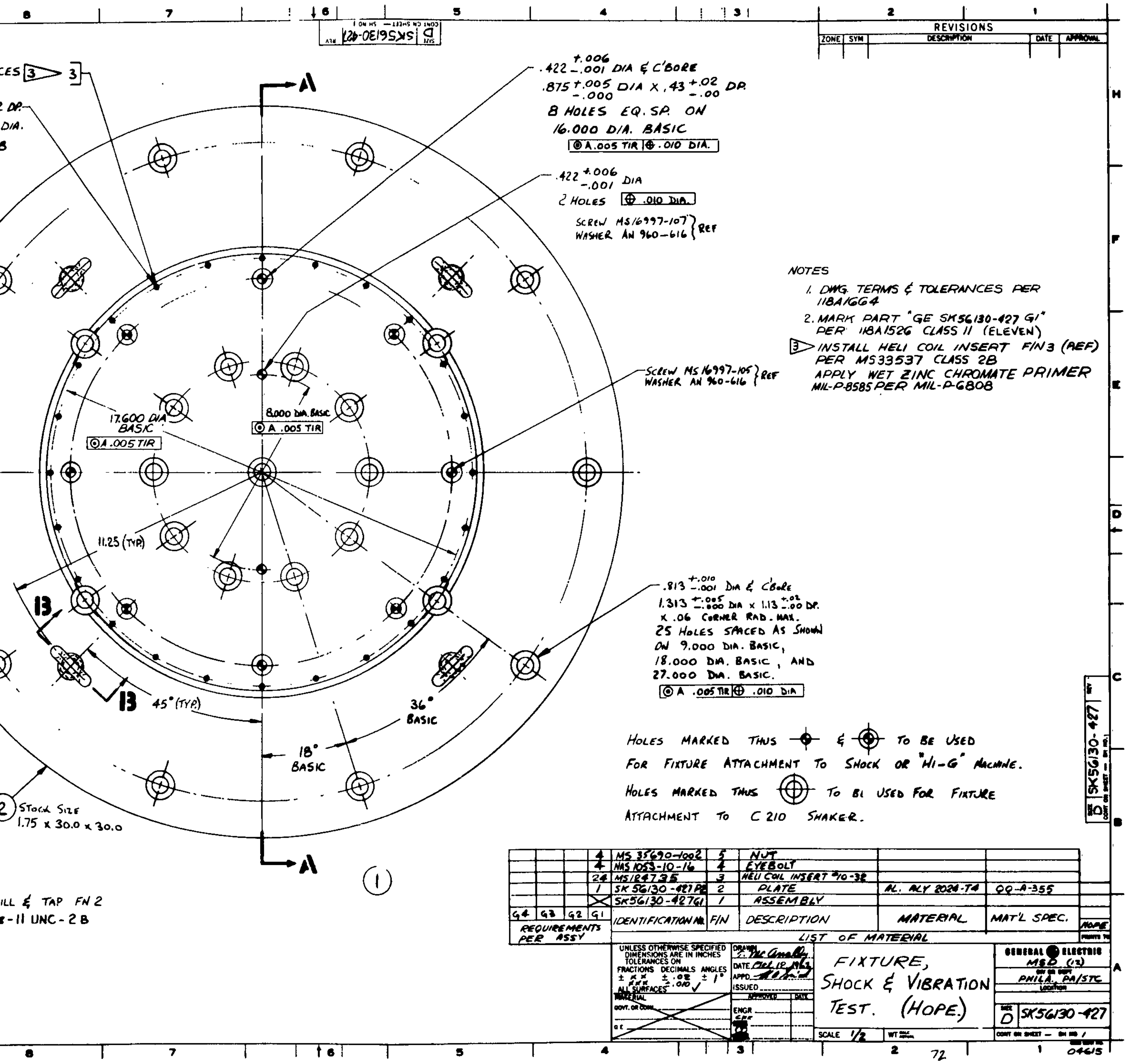


Figure 5-5. Test Capsule and Chamber Installation

2


TYP 24 PLACES
.196 +.005 -.001 DIA x .62±.02 DP.
CSK 120° TO .25 +.00 -.02 DIA.
¼ HELICOIL TAP #3FSB
x .45 ±.02 DP.
24 HOLES EQ. SP.
.010 DIA.
-A-
-B-
30.00 DIA.
18.040 +.000 -.015 DIA.
17.600 DIA BASIC
A .005 TIR
8.000 DIA. BASIC
A .005 TIR
11.25 (TYP)
45° (TYP)
36° BASIC
18° BASIC
.06 R MAX. TYP.
.25
.03 RAD MAX
.300
1.62
2 STOCK SIZE 1.75 x 30.0 x 30.0
SECTION A—A
2.50 APPROX
DRILL & TAP FN 2
5/8-11 UNC-2B
SECTION B—B
(TYP. 4 PLACES)
D SKS6130-421

1



2

Figure 5-6. Fixture, Shock and Vibration Test (HOPE)

5.7 WEIGHT STATUS

The weights reported for the HOPE spacecraft at the close of the reporting period are as noted below:

Oxygen Compartment Assembly		22.32 lb.
Dome Assembly	4.09 lb.	
Gas Storage Tank	8.37	
Strap Assembly	.89	
Tank Adjusters	.18	
Tank Pads	.50	
Pad Cushions	.06	
Spring Washers	.17	
Misc. Items (grease, etc.)	.10	
O_2 Gas at 70°F	7.46	
Instrumentation	.50	
Hydrogen Compartment Assembly		35.31 lb.
Structural Assembly	9.78 lb.	
Gas Storage Tank	18.53	
Strap Assembly	1.02	
Tank Adjusters	.16	
Tank Pads	.54	
Pad Cushions	.06	
Spring Washers	.18	
Misc. Items (grease, etc.)	.10	
H_2 Gas at 70°F	.94	
Antennas (4)	4.00	
Electrical Compartment Assembly		58.55 lb.
Structural Assembly	12.55 lb.	
Signal Data Converter	4.00	
Battery	8.50	
Encoder	3.30	
Transmitter	1.50	
Power Control	8.00	
Fuel Cell Controller	13.00	
Fuel Supply Shutoff	2.00	
Sensor Power Supply	.50	
Electrical Umbilicals	2.50	
Mounting Provisions	2.50	
Misc. Items	.50	

Experiment Compartment Assembly		65.35 lb.
Structural Assembly	13.74 lb.	
Water Tank	6.60	
Radiator/Fuel Cell Assembly (2)	42.32	
Cradle Assembly	.46	
Strap Assembly	.46	
Compartment Assembly Fasteners	.77	
Instrumentation	1.00	
Despin Compartment Assembly		12.95 lb.
Despin Adapter	8.95 lb.	
Despin Mechanism	2.50	
Despin Controller	1.50	
Overall Vehicle Assembly		43.70 lb.
Insulation Installation	10.90 lb.	
Pneumatics Installation	16.00	
Electrical Harness	12.40	
Terminal Blocks and Mounts	1.70	
Cooling Manifold	1.50	
Vehicle Assembly Fasteners	1.20	

Summary

This listing gives a total weight of the spacecraft, exclusive of booster fourth stage, of 238.18 lb.

5.8 STRUCTURAL DESIGN SPECIFICATIONS

Some changes to the design specifications occurred during Phase Ia due to better booster motor information. These changes are discussed below:

5.8.1 Vibration

Maximum vibration inputs to the spacecraft from the booster fourth stage motor at the spacecraft motor interface were taken as follows. These figures are from RECOMMENDED MECHANICAL ENVIRONMENTAL TEST LEVELS FOR DESIGN QUALIFICATION AND FLIGHT ACCEPTANCE TESTING OF SCOUT LAUNCHED SPACECRAFT, dated August 8, 1962, from Scout Project Group-NASA, LRC.

Frequency (cps)	Axial (g's)	Lateral (g's)
5 - 10	0.4" D.A.	0.2" D.A.
10 - 50	2.0	1.0
50 - 500	6.0	1.5
500 - 2000	12.0	2.5

These levels were to be used as prototype test levels. Flight acceptance levels for the spacecraft were as follows, taken from the same source:

Frequency (cps)	Axial (g's)	Lateral (g's)
20 - 50	1.0	.6
50 - 500	4.0	.8
500 - 2000	8.0	1.6

5.8.2 Shock

Shock test levels for prototype was changed to 30 g's for a period of 10 to 15 milliseconds. For flight article this level would be reduced to 20 g's for the same period. Again, the same source as for 5.8.1 was used.

5.8.3 Other Test Levels

All other test levels remain as detailed in the Phase I Final Report.

5.9 SPACECRAFT ANALYSIS

Stress Analysis of the HOPE spacecraft during Phase Ia consisted of: (1) A complete re-analysis of the vibration response of the structure using a technique developed on the NIMBUS program; and (2) structural analysis of those areas of the spacecraft modified by Phase Ia design.

5.9.1 Dynamic Analysis

A dynamic analysis computer routine developed by the NIMBUS program was used in HOPE Phase Ia to check the spacecraft structure for dynamic response to the expected vibration inputs. This routine has been exhaustively checked against vibration test results from the NIMBUS spacecraft and is considered highly reliable.

In the dynamic analysis for Phase I, a so-called dashpot damping technique was used. Here, the amount of damping is a function of the component masses. Some knowledge of the characteristic response of the masses to dynamic excitation is required to establish intelligent damping valves for each dashpot. Since no such data was available in Phase I, only estimates based on experience could be used.

For Phase Ia, a new technique for dynamic analysis was available called modal damping. In this concept, damping is considered to be an inherent property of the materials of construction. The damping coefficient is the same for each spring in the system and was put at 5% in the longitudinal mode and 7.5% in the lateral mode.

A four degree of freedom system was set up for the analysis. Masses and spring constants used are shown in Figure 5-7. Two different values are shown for the upper pair of spring rates, the lower rate representing the value with rubber dampers placed between the compartments. Analyses were run both with and without the rubber dampers.

Results of these investigations are summarized in Figures 5-8 and 5-9 and in Table 5-1 below:

TABLE 5-1

RESONANT FREQUENCIES

DIRECTION	FREQUENCY (CPS)							
	1st Mode		2nd Mode		3rd Mode		4th Mode	
	With Dampers	Without Dampers	With Dampers	Without Dampers	With Dampers	Without Dampers	With Dampers	Without Dampers
Longitudinal	166.5	184	360	506	535	670	838	858
Lateral	66.2	70	140	192	217	258	322	328

It is immediately apparent that addition of rubber dampers (gaskets) does not lower the resonant frequencies to frequency band widths with lower input levels. For this reason, use of rubber gaskets to reduce spacecraft spring rates was no longer considered in Phase Ia.

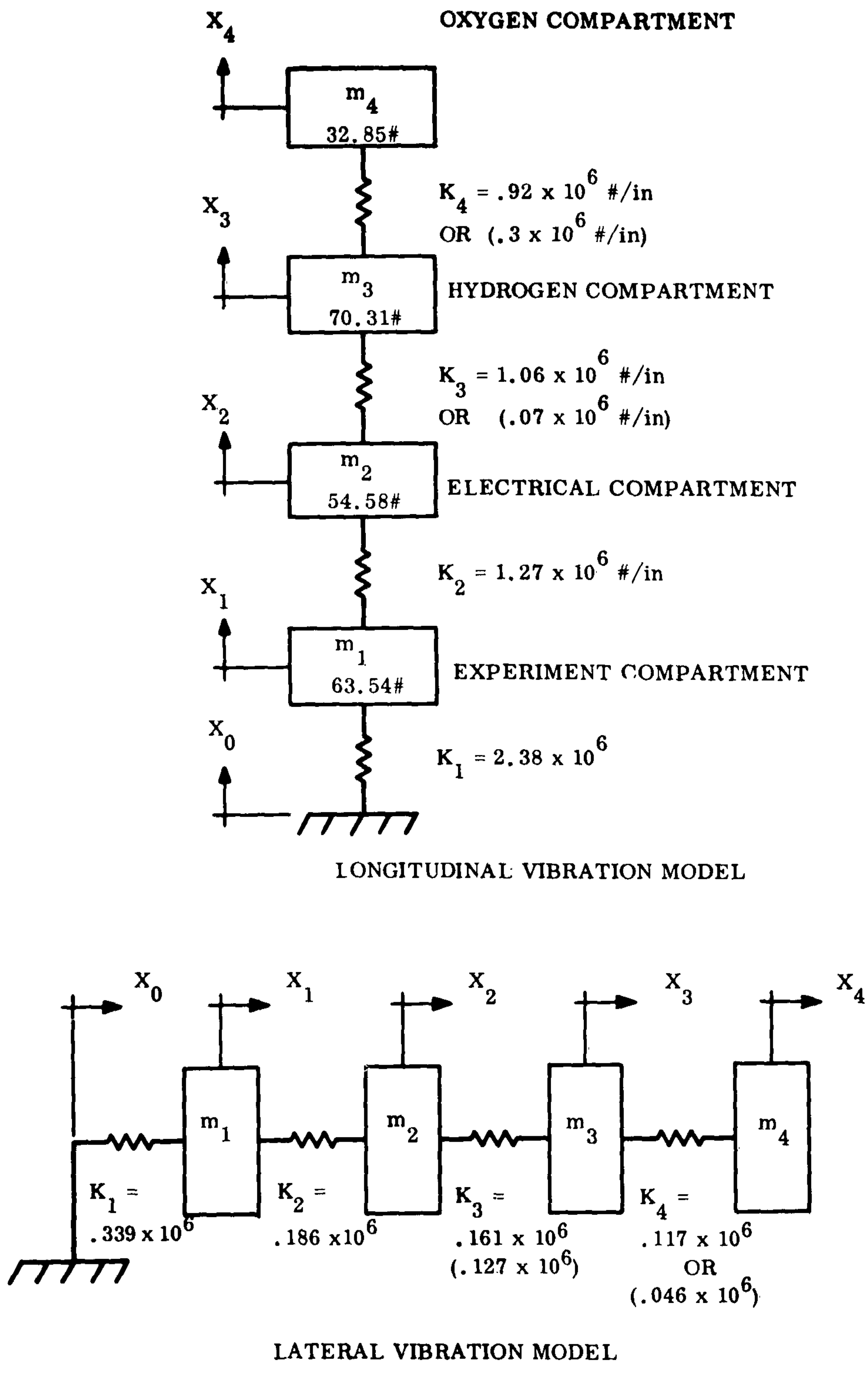
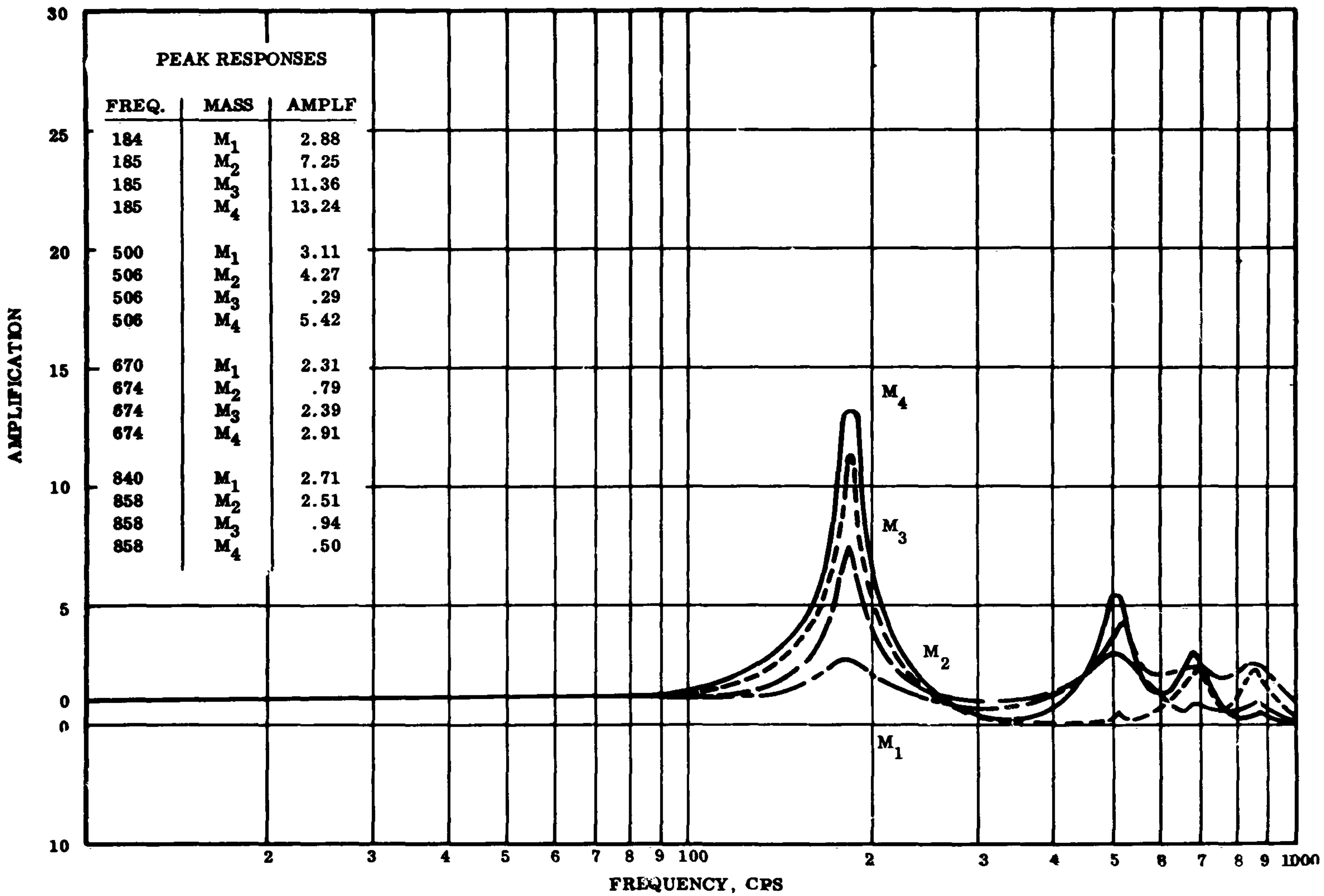


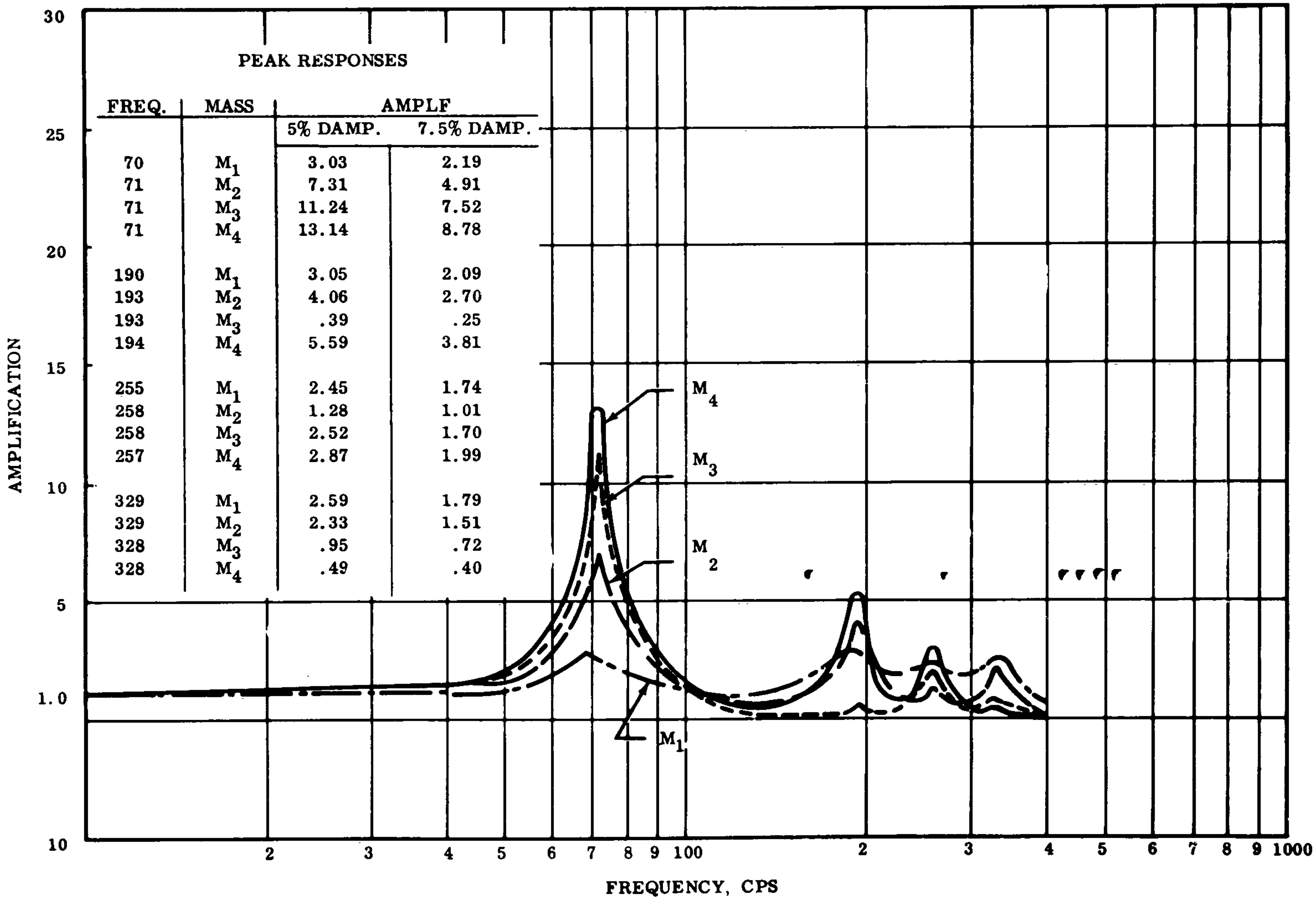
Figure 5-7. Longitudinal and Lateral Vibration Models



PEAK RESPONSES

FREQ.	MASS	AMPLF
184	M_1	2.88
185	M_2	7.25
185	M_3	11.36
185	M_4	13.24
500	M_1	3.11
506	M_2	4.27
506	M_3	.29
506	M_4	5.42
670	M_1	2.31
674	M_2	.79
674	M_3	2.39
674	M_4	2.91
840	M_1	2.71
858	M_2	2.51
858	M_3	.94
858	M_4	.50

Figure 5-8. Response of HOPE Vehicle to Longitudinal Vibration (No Dampers) 5% Damping



FREQ.	MASS	AMPLF 5% DAMP.	AMPLF 7.5% DAMP.
70	M_1	3.03	2.19
71	M_2	7.31	4.91
71	M_3	11.24	7.52
71	M_4	13.14	8.78
190	M_1	3.05	2.09
193	M_2	4.06	2.70
193	M_3	.39	.25
194	M_4	5.59	3.81
255	M_1	2.45	1.74
258	M_2	1.28	1.01
258	M_3	2.52	1.70
257	M_4	2.87	1.99
329	M_1	2.59	1.79
329	M_2	2.33	1.51
328	M_3	.95	.72
328	M_4	.49	.40

Figure 5-9. Response of HOPE Vehicle to Lateral Vibration (No Dampers) 5% Damping Shown

5.9.2 Structural Analysis

5.9.2.1 Critical Design Conditions

The critical flight and testing design conditions are summarized as follows:

- Condition I — + Dynamic (vibration) Axial Loads (testing).
- Condition II — - Dynamic (vibration) Axial - Static (acceleration) (flight).
- Condition III — $\pm$ Dynamic (vibration) Lateral (testing).
- Condition IV — $\pm$ Dynamic (vibration) Lateral $\pm$ Static Lateral - Static (acceleration) (flight).
- Condition V — - 15.1 g's Static (acceleration) (flight).

Condition I - Represents the dynamic testing of the vehicle in the longitudinal direction and is the design condition for the longerons, bathtub fittings and the tension joints between the compartments.

Condition II - Is composed of superimposed flight static (acceleration) and dynamic (vibration) longitudinal loadings at maximum dynamic pressure. This condition is critical for components and component mountings in the Oxygen, Hydrogen, Electrical and Experiment Compartments.

Condition III - The design testing of the vehicle in the lateral direction is not a critical design condition and is included for reference only.

Condition IV - Is a superposition of flight static (acceleration) and dynamic (vibration) lateral loads and static longitudinal loads at maximum dynamic pressure. The vehicle skins, which carry the shear, are designed for this condition.

Condition V - Is the static acceleration at booster burnout and designs the components and their mountings in the despin compartment.

5.9.2.2 Sign Conventions

Inertia loads acting aft due to acceleration of the vehicle are considered negative (-), and those acting forward due to acceleration are considered positive (+). Loads due to lateral accelerations are considered to act in either direction ($\pm$)

and, therefore, are used in connection with axial loads such that they are additive. Loads due to vibrations act in either direction (±) and, therefore, are used in connection with lateral and axial loads such that they are additive.

5.9.2.3 Loading Diagrams

Axial load, shear and bending moment diagrams, as applicable, are presented as Figures 5-10 through 5-14. The unit or lg loading diagram, Figure 5-10 is made up from distributed equipment and structure weights and is corrected from that shown in the Phase I Report to account for changes in equipment weights and locations.

5.9.3 Calculated Amplification Factors Through the Spacecraft

AXIAL CASE (f = 185 cps)

Inches from Nose	Amplification
0 - 13.33	13.23
13.33 - 30.18	11.36
30.18 - 42.73	7.25
42.73 - 64.73	2.75
64.73 - 71.28	1.00

LATERAL CASE (f = 71 cps)

Inches from Nose	Amplification
0 - 13.33	8.78
13.33 - 30.18	7.52
30.18 - 42.73	4.91
42.73 - 64.73	2.06
64.73 - 71.28	1.00

5.10 Spacecraft Status

Figures 5-15 through 5-19 show photographs of the assembled DTV and selected installations. Figure 5-20 is a photograph of tooling used during the fabrication of the DTV. Figure 5-21 consists of the HOPE drawing tree.

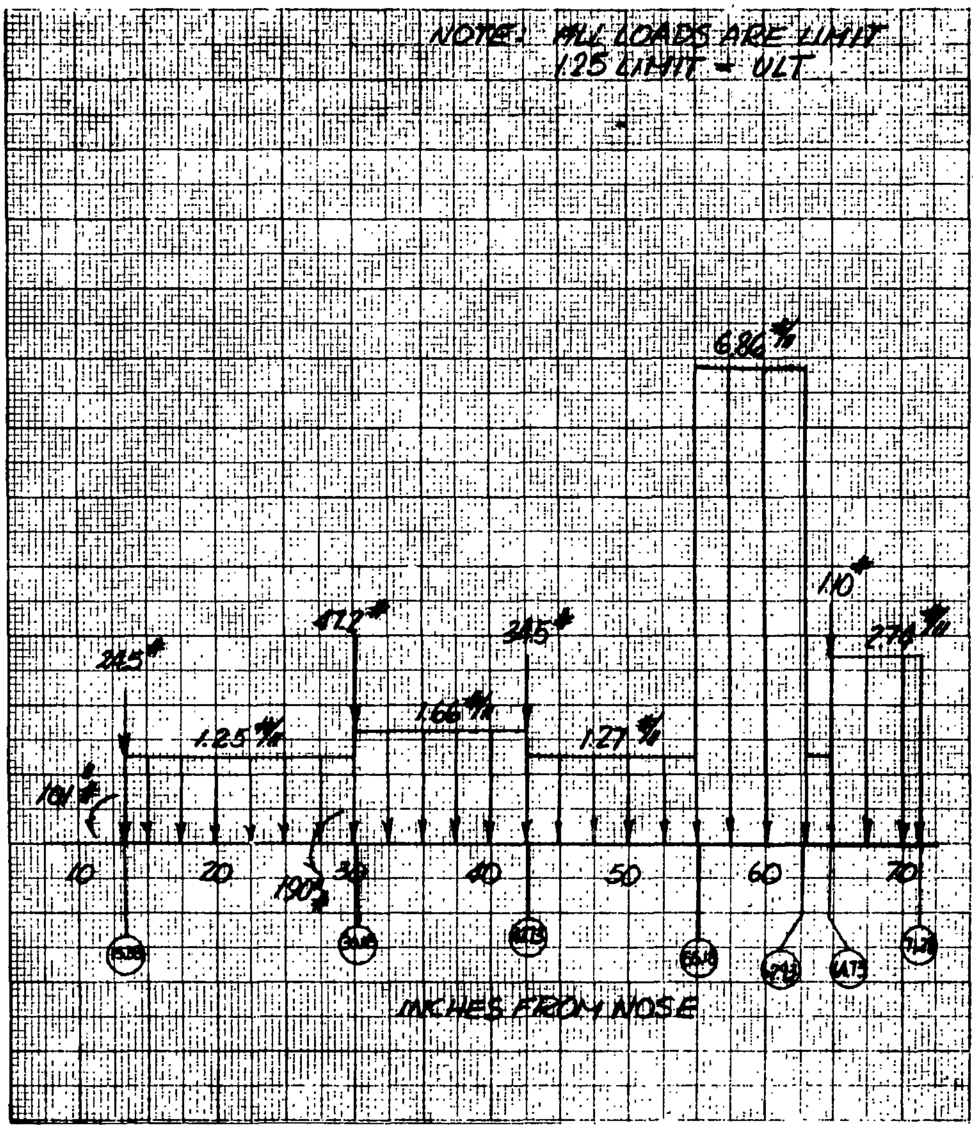


Figure 5-10. HOPE - Phase 1A, Vehicle Loading Diagram (1G)

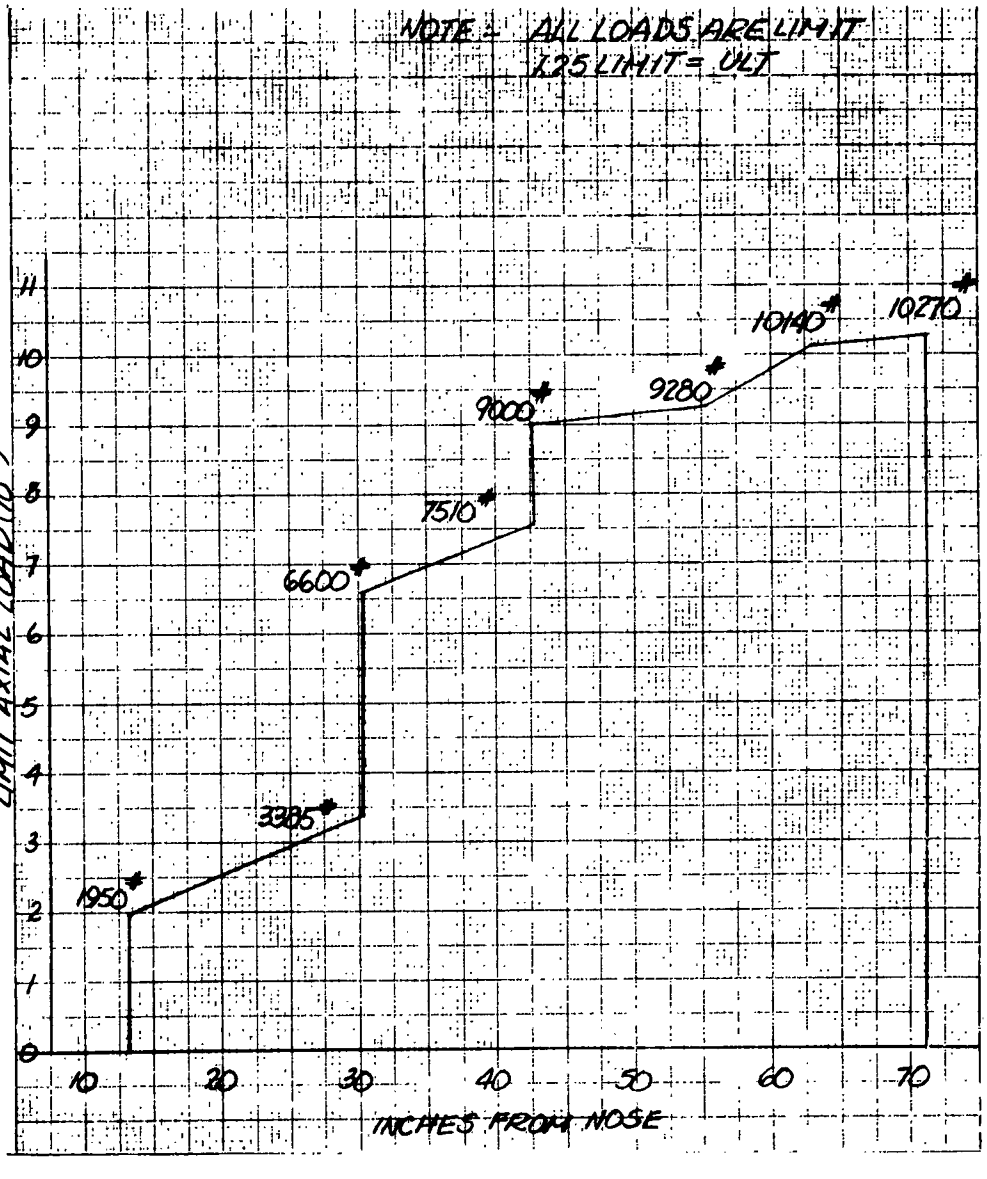


Figure 5-11. HOPE - Phase 1A, Vehicle Load Condition I Axial Load Diagram, Dynamic Prototype Testing

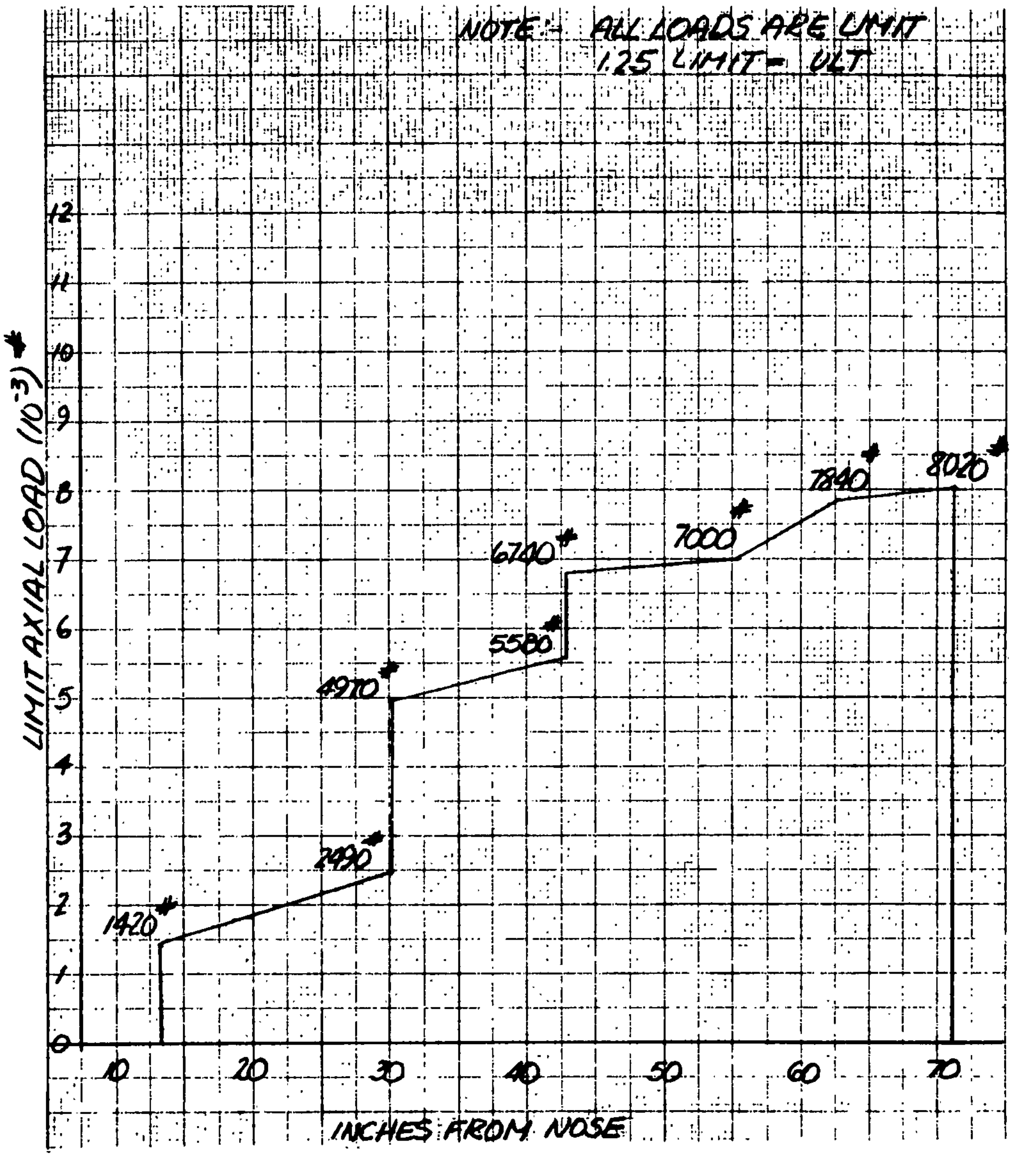


Figure 5-12. HOPE - Phase 1A, Vehicle Load Condition II Axial Load Diagram, - Dynamic Axial (Flight Acceptance) 5g's Tnrust

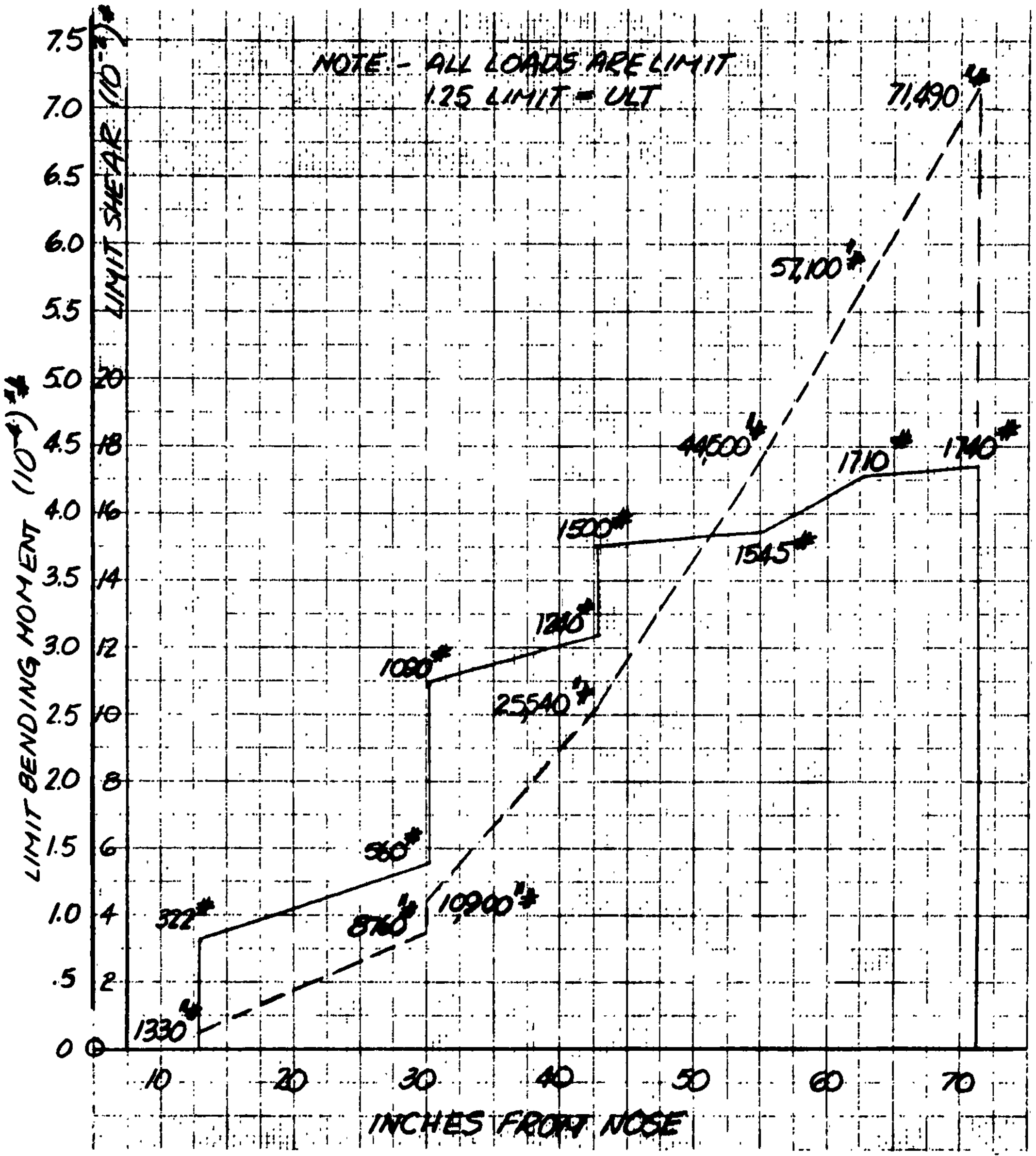


Figure 5-13. HOPE - Phase 1A, Vehicle Load Condition III
Shear and Bending Moment Diagrams
Dynamic Prototype Testing

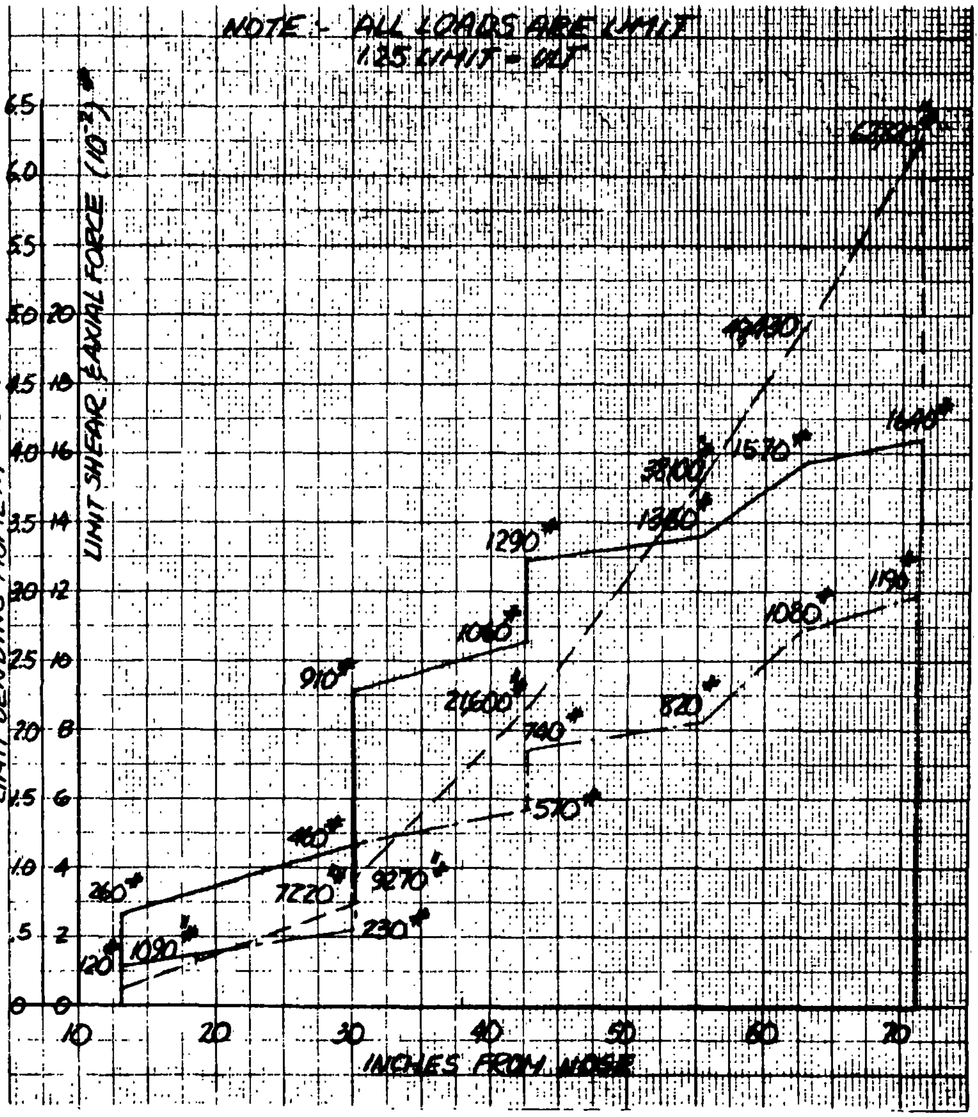


Figure 5-14. HOPE - Phase 1A, Vehicle Load Condition IV Shear, Bending Moment, & Axial Force Diagrams Dynamic Lateral (Flight Acceptance) + 2g Static Lateral + 5 g's Thrust

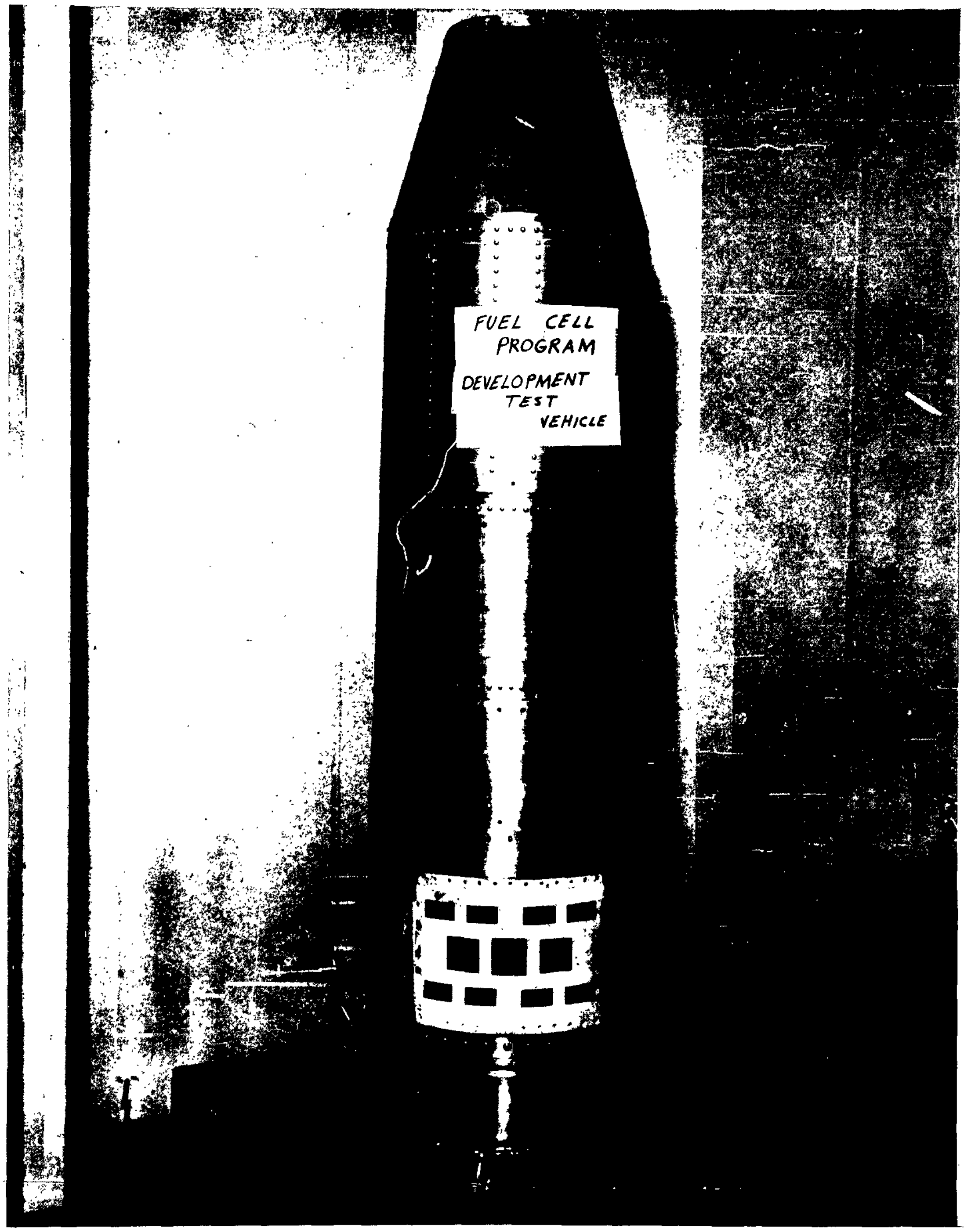


Figure 5-15. Fuel Cell Program-Development Test Vehicle

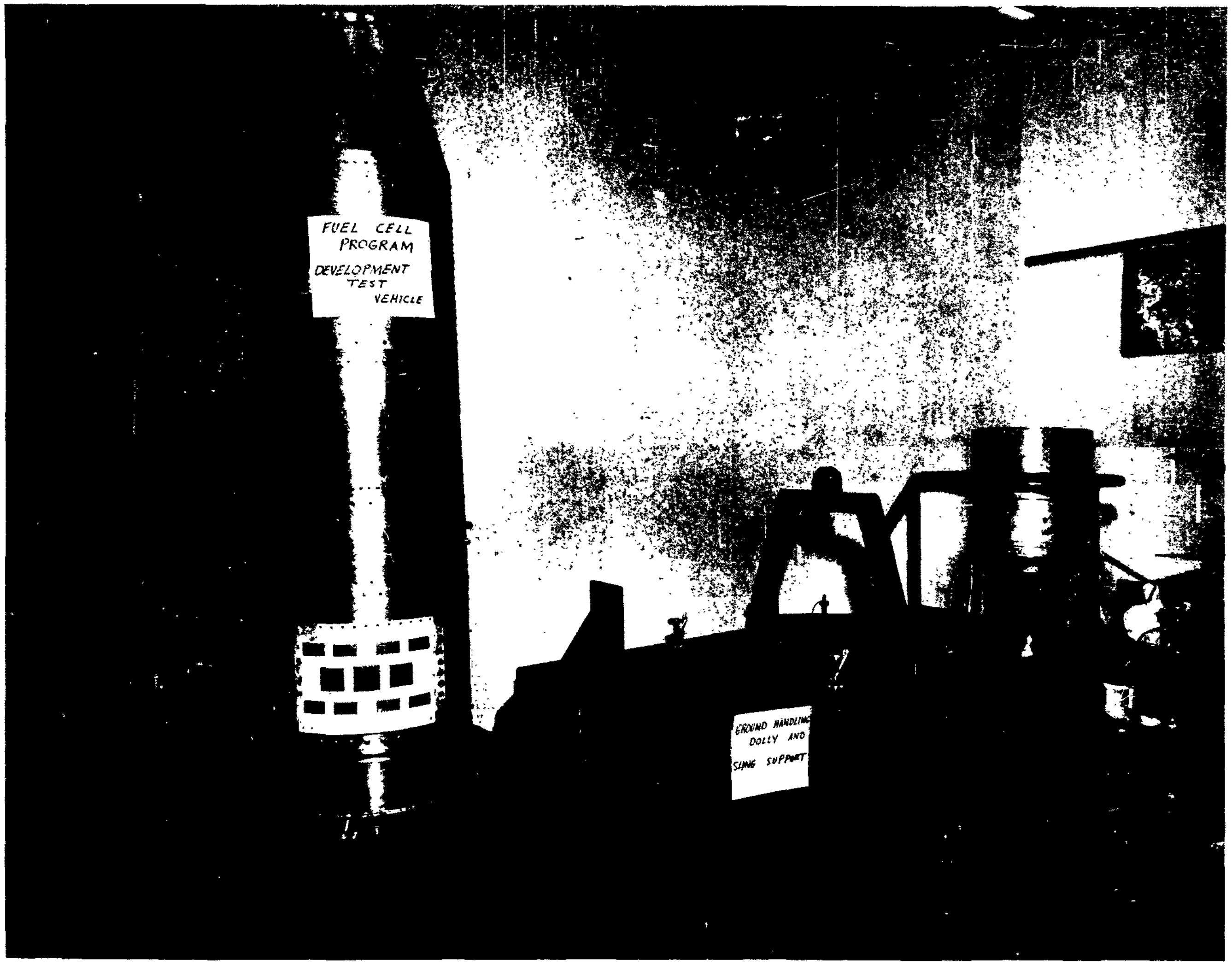


Figure 5-16. Ground Handling Dolly and Sling Support

Figure 5-17. Fuel Cell Program Development Test Vehicle

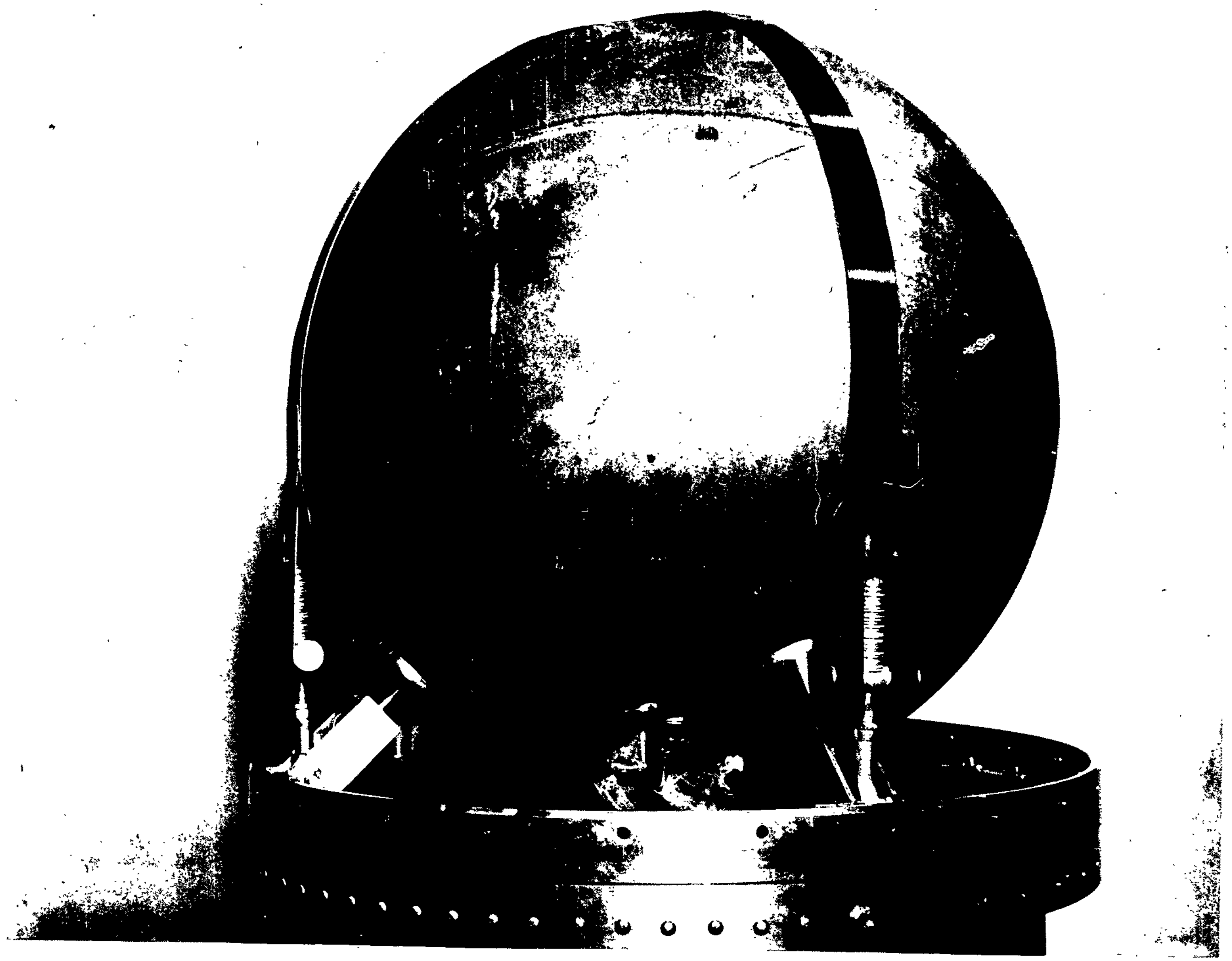


Figure 5-18. Tank for Pressurized Gas

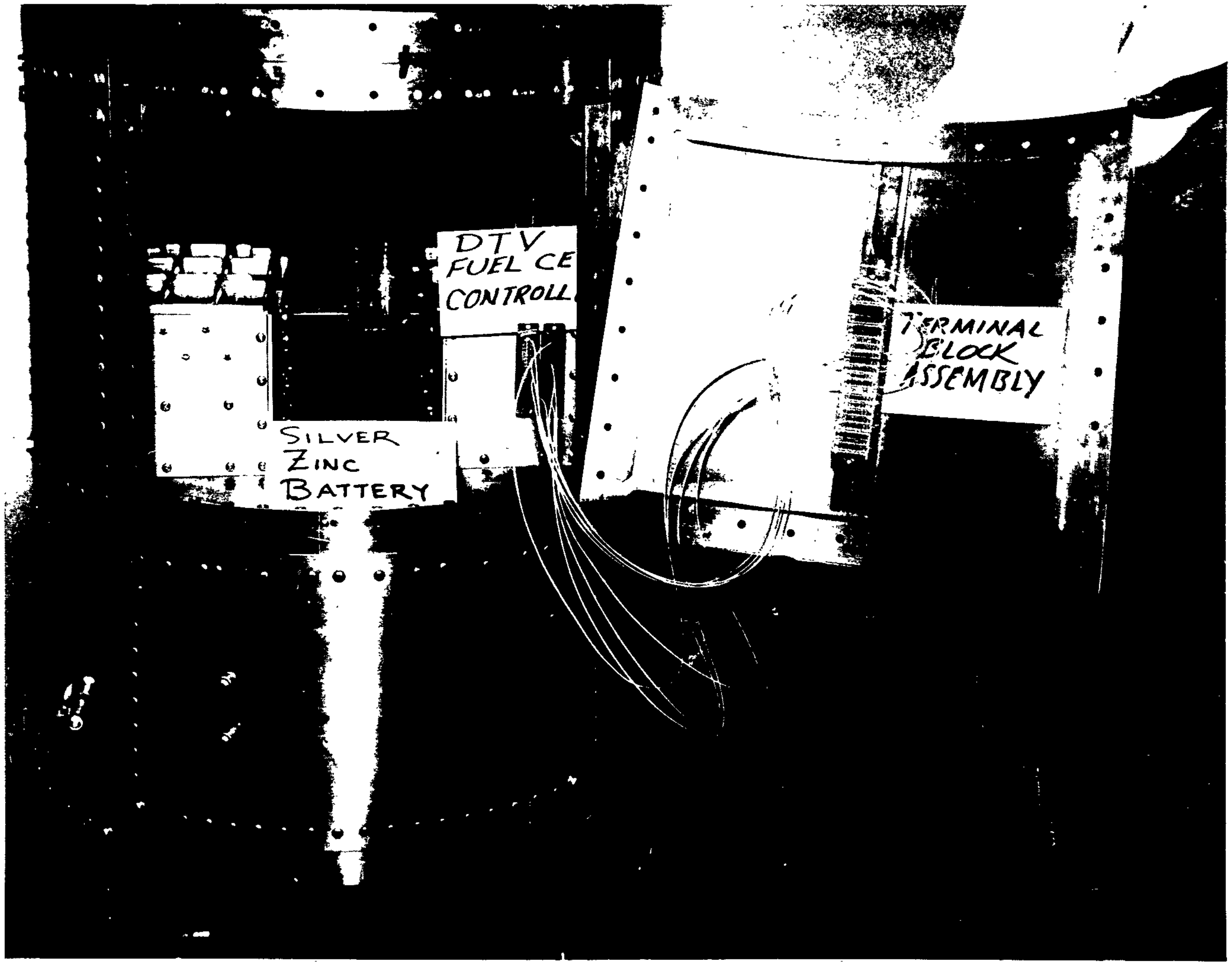


Figure 5-19. DTV Fuel Cell Controller and Silver Zinc Battery

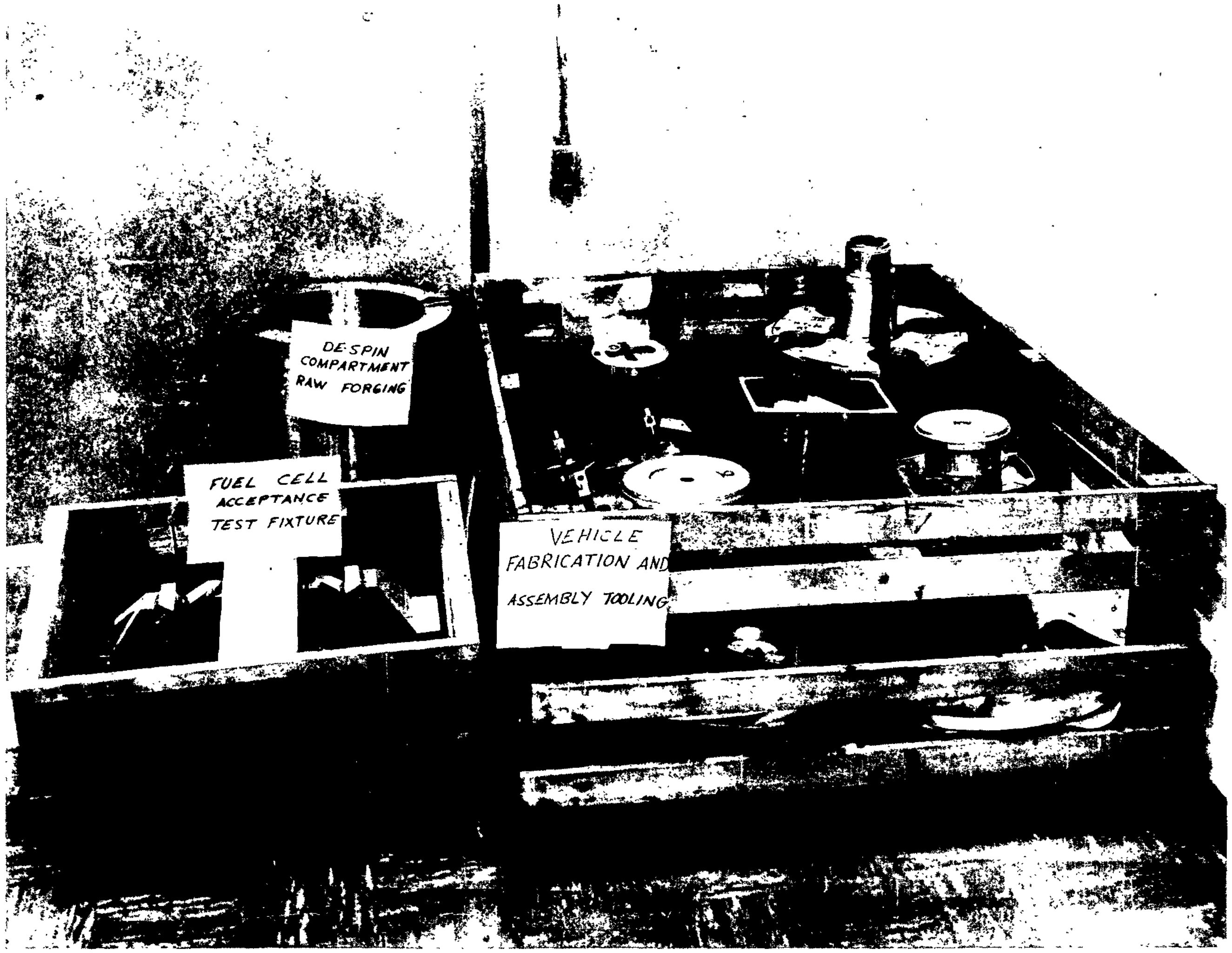
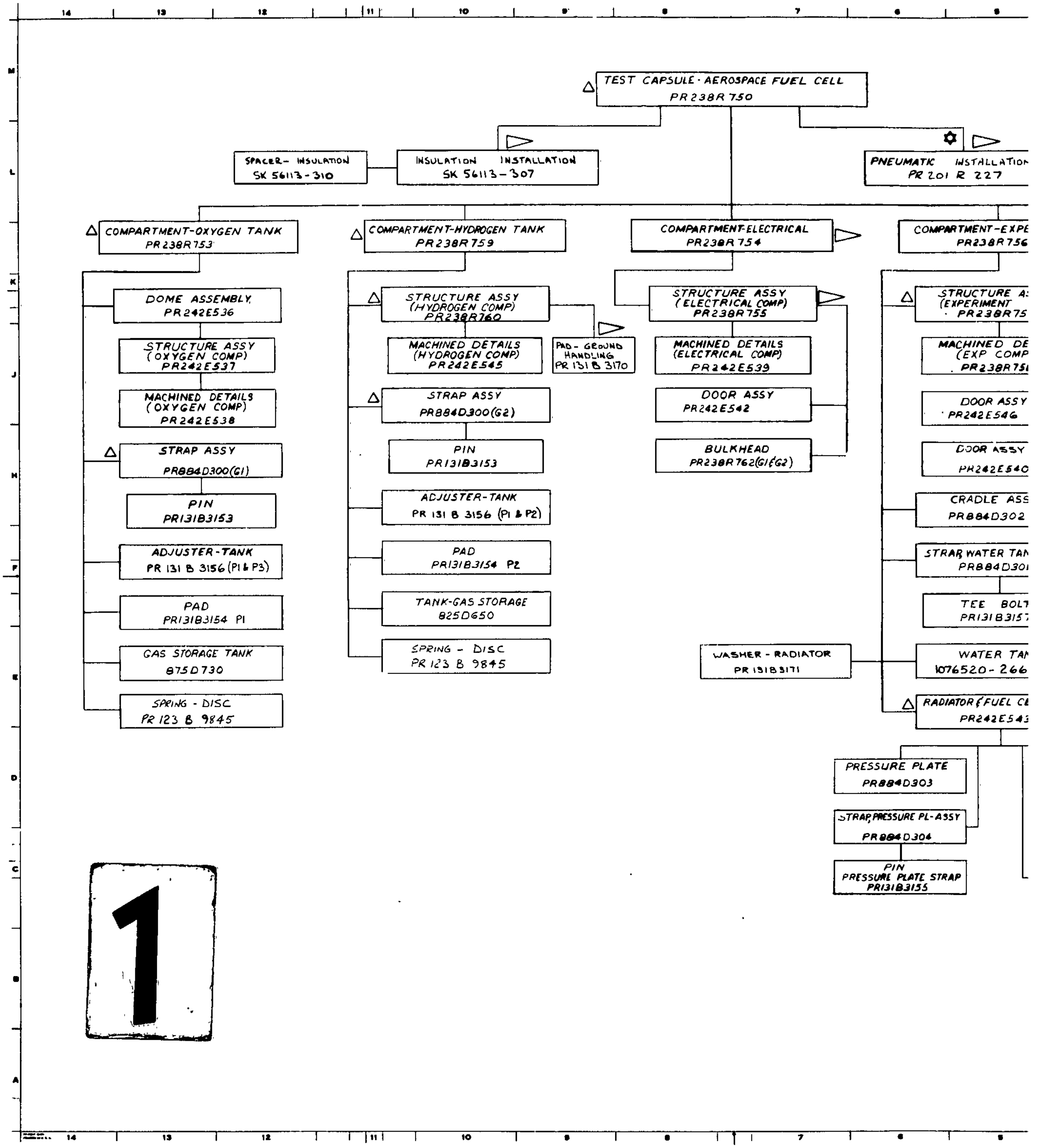


Figure 5-20. Various Tooling Used During DTV Fabrication


TEST CAPSULE - AEROSPACE FUEL CELL
PR 238R 750
SPACER - INSULATION
SK 56113-310
INSULATION INSTALLATION
SK 56113-307
PNEUMATIC INSTALLATION
PR 201 R 227
COMPARTMENT-OXYGEN TANK
PR 238R753
COMPARTMENT-HYDROGEN TANK
PR238R759
COMPARTMENT-ELECTRICAL
PR238R754
COMPARTMENT-EXPE
PR238R756
DOME ASSEMBLY
PR242E536
STRUCTURE ASSY (OXYGEN COMP)
PR242E537
MACHINED DETAILS (OXYGEN COMP)
PR242E538
STRAP ASSY
PR884D300(G1)
PIN
PR131B3153
ADJUSTER-TANK
PR 131 B 3156 (P1 & P3)
PAD
PR131B3154 P1
GAS STORAGE TANK
875D730
SPRING - DISC
PR 123 B 9845
STRUCTURE ASSY (HYDROGEN COMP)
PR238R760
PAD - GROUND HANDLING
PR 131 B 3170
MACHINED DETAILS (HYDROGEN COMP)
PR242E545
STRAP ASSY
PR884D300(G2)
PIN
PR131B3153
ADJUSTER-TANK
PR 131 B 3156 (P1 & P2)
PAD
PR131B3154 P2
TANK-GAS STORAGE
825D650
SPRING - DISC
PR 123 B 9845
STRUCTURE ASSY (ELECTRICAL COMP)
PR238R755
MACHINED DETAILS (ELECTRICAL COMP)
PR242E539
DOOR ASSY
PR242E542
BULKHEAD
PR238R762(G1&G2)
WASHER - RADIATOR
PR 131B3171
STRUCTURE A (EXPERIMENT
PR238R75
MACHINED DE (EXP COMP
PR238R75
DOOR ASSY
PR242E546
DOOR ASSY
PR242E540
CRADLE ASS
PR884D302
STRAP WATER TAN
PR884D30
TEE BOLT
PR131B315
WATER TAN
1076520-266
RADIATOR & FUEL CE
PR242E54
PRESSURE PLATE
PR884D303
STRAP, PRESSURE PL-ASSY
PR884D304
PIN PRESSURE PLATE STRAP
PR131B3155
1

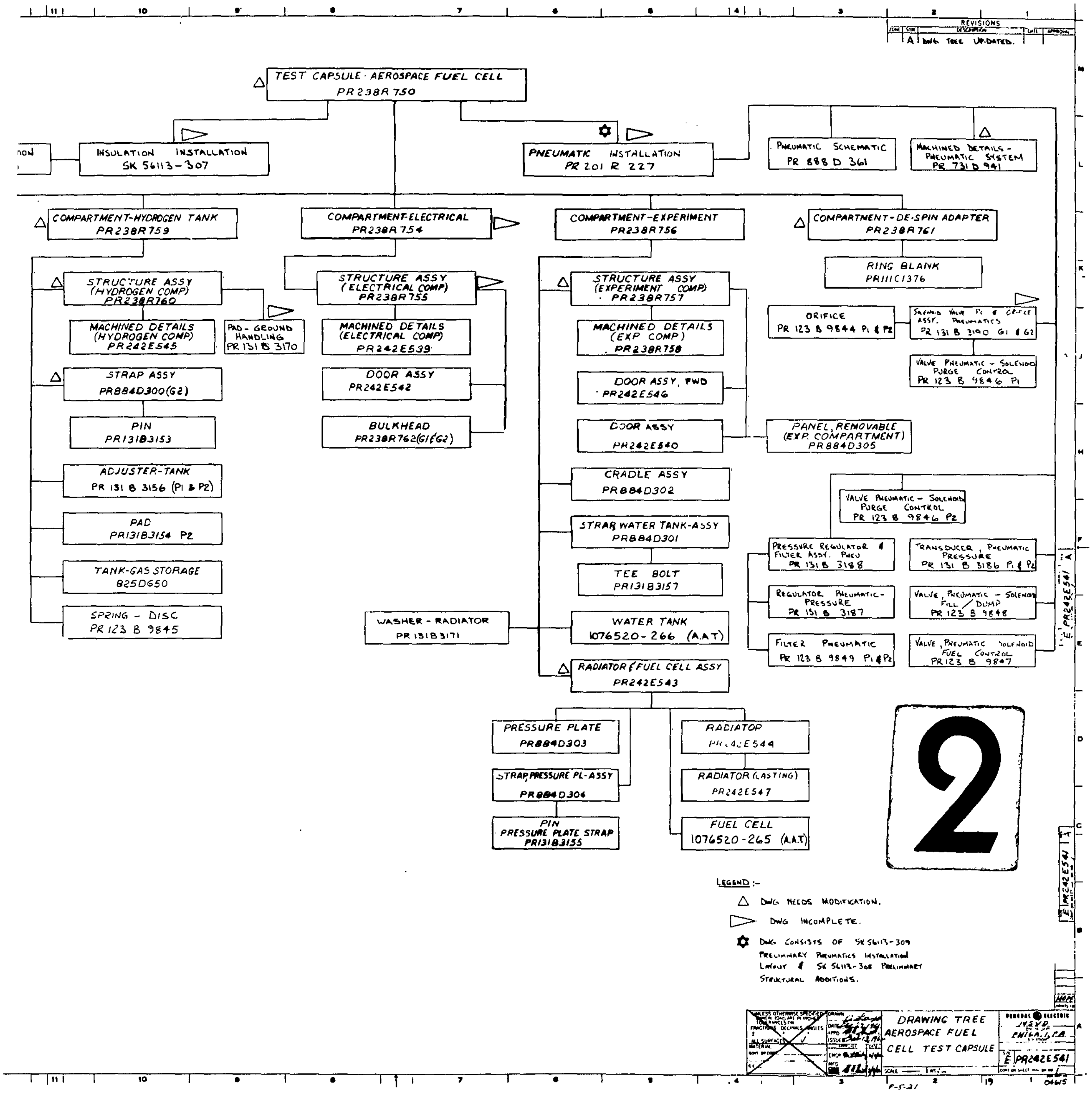


Figure 5-21. Drawing Tree, Aerospace Fuel Test Capsule

SECTION 6

GROUND TEST SYSTEM

J. Messingschlager

6.0 GROUND TEST SYSTEM

6.1 INTRODUCTION

The ground test system for the HOPE program consists of a transportation and support dolly, a lifting sling, and a pneumatic package for servicing the spacecraft during tests and ground checkout prior to launch.

6.2 DOLLY ASSEMBLY

Fabrication drawings of the dolly assembly, Figure 6-1 were revised the previous quarter and a requisition was issued to manufacture one assembly. The unit was fabricated and delivered October 10, 1962. Figures 6-2 and 6-3 are photographs which show front and rear views of the bearing housing assembly when the spacecraft spin axis is in the horizontal attitude. Figures 6-4 and 6-5 are photographs showing the bearing housing assembly rotated 90°, placing the spacecraft spin axis in a vertical position.

The dolly assembly is completed except for an interface coupling between the sling and the dolly assemblies. The coupling would provide two optional methods of supporting the spacecraft: (1) The original cantilever support of the despin housing when the dolly is stationary and (2) a rigid two-point support system when transporting the spacecraft with the dolly. This interface coupling has been designed, however, it must still be incorporated in the dolly assembly.

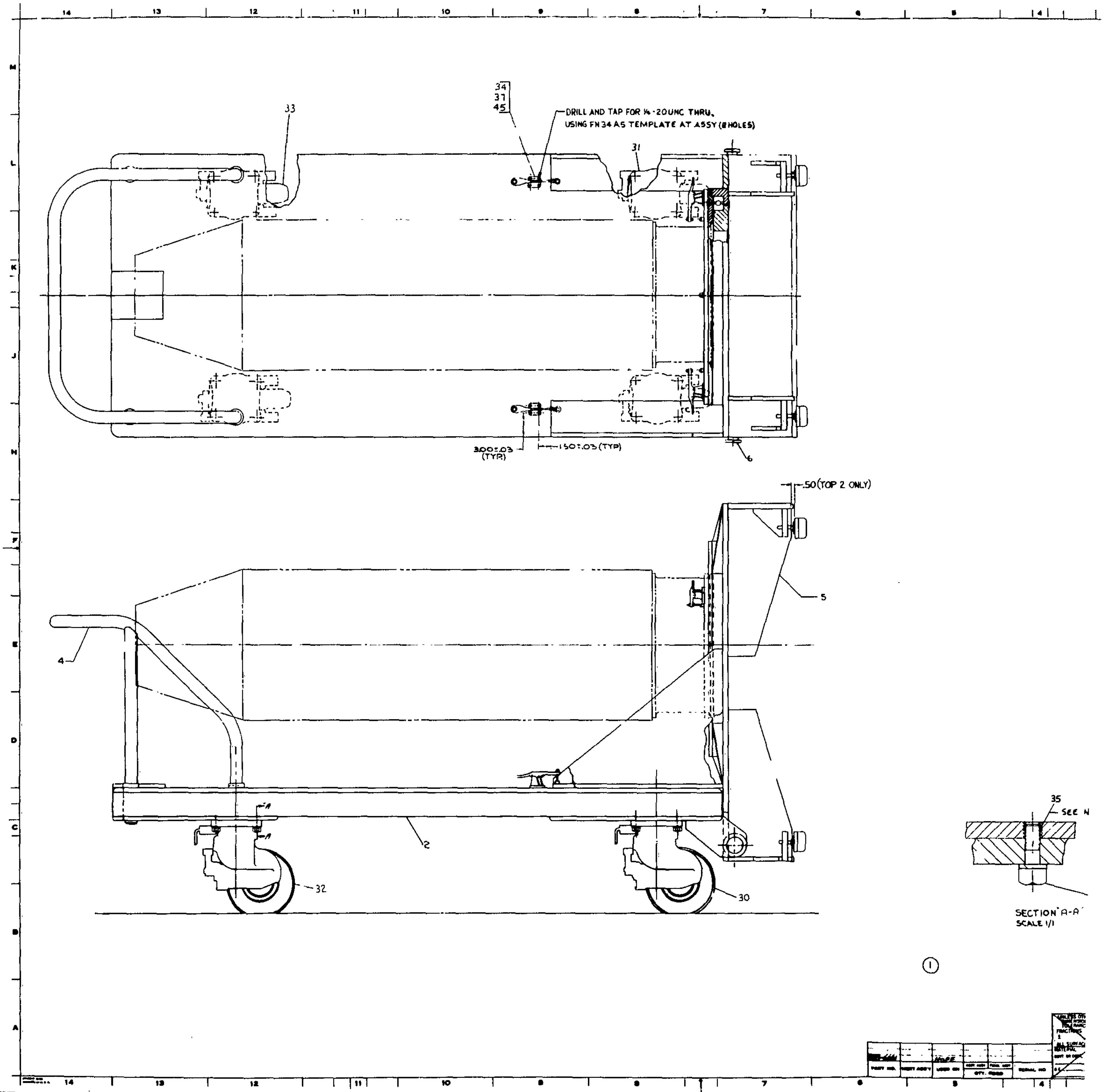
6.3 SLING ASSEMBLY

Drawings of the sling assembly, renamed the lifting and support assembly, Figure 6-6 , were completed. Figures 6-7 and 6-8 are photographs showing the attitude of the lifting and support assembly when used in conjunction with the dolly assembly.

Figure 6-9 is a lifting diagram which indicates the general operational relationship between the dolly assembly, the HOPE spacecraft and the lifting and support assembly.

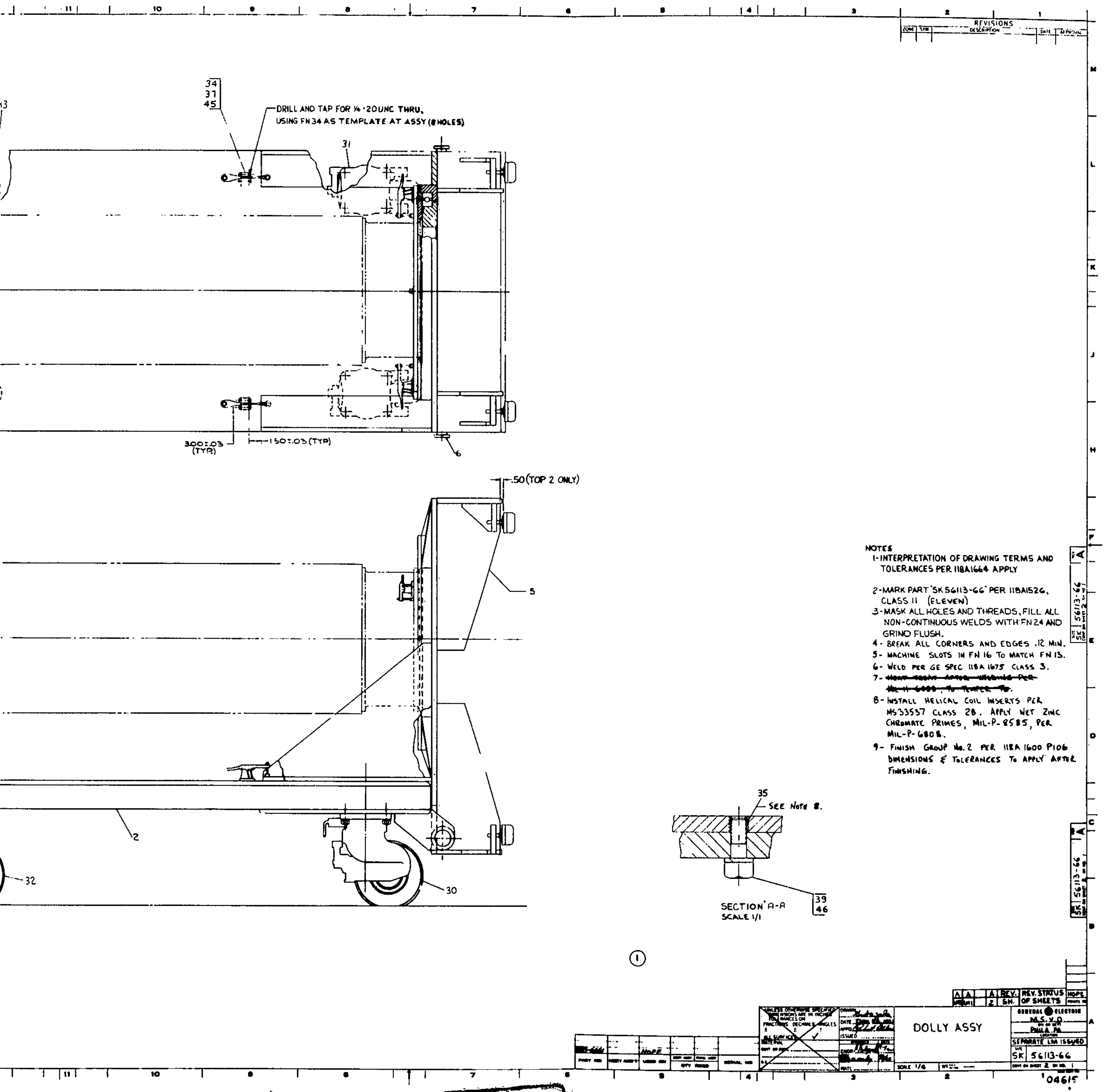
6.4 GROUND SERVICE PACKAGE

Three pneumatic ground service systems, outlined in the last Quarterly Report, were reviewed from engineering, delivery, and cost aspect and the third system selected for the HOPE program. Briefly, the selected system utilizes four commercial bottles of pre-purified (99.96%) hydrogen, and one bottle of commercially pure (99.5%) oxygen to pre-charge the fuel tanks to 1650 psig and 1610 psig, respectively. After the pre-charging equalization pressure is attained the



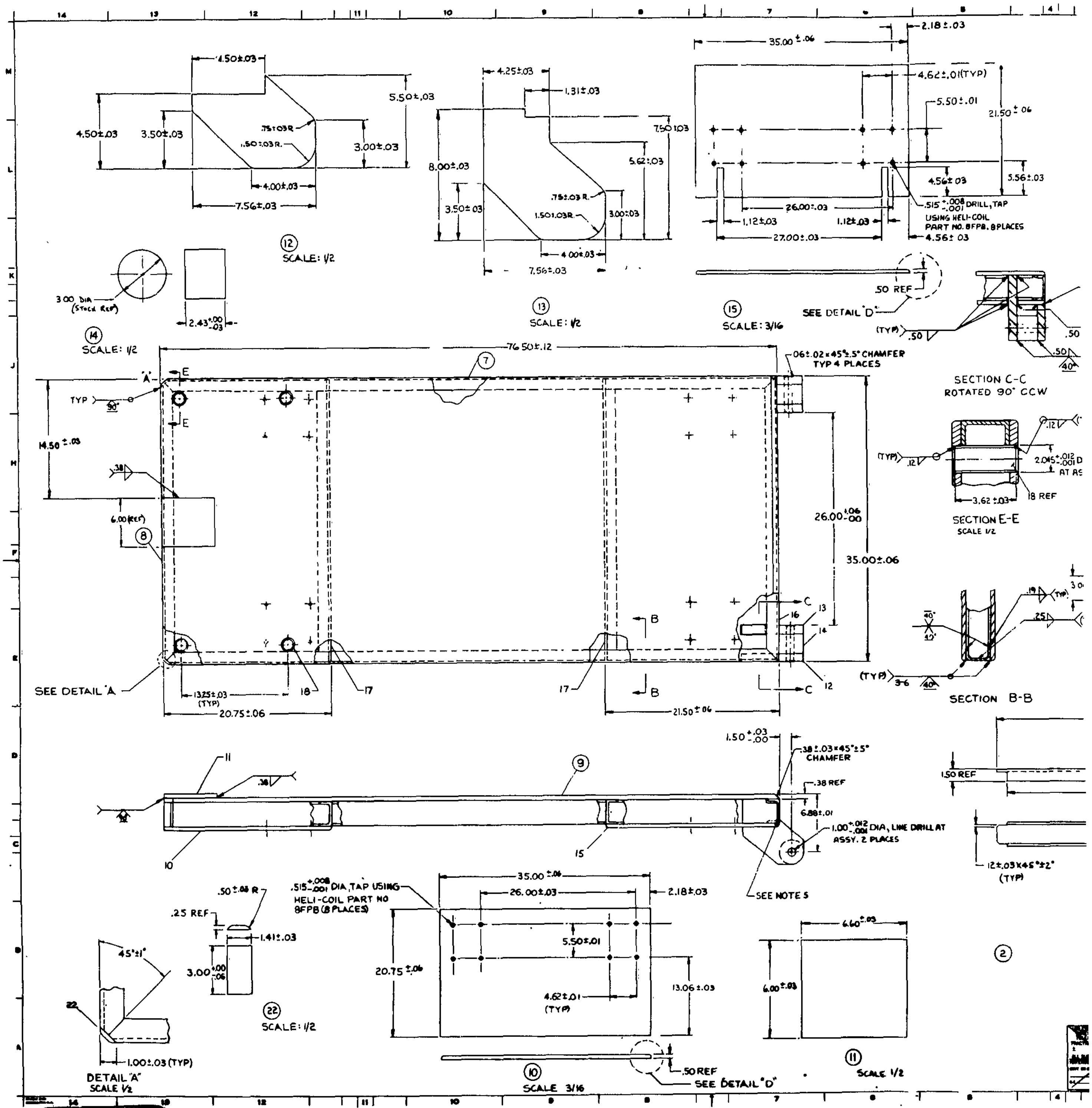
34
31
45
DRILL AND TAP FOR ¼-20UNC THRU, USING FN34 AS TEMPLATE AT ASSY (8 HOLES)
33
31
3.00±.03 (TYP)
1.50±.03 (TYP)
6
.50 (TOP 2 ONLY)
5
4
2
32
30
35
SECTION A-A
SCALE 1/1

1



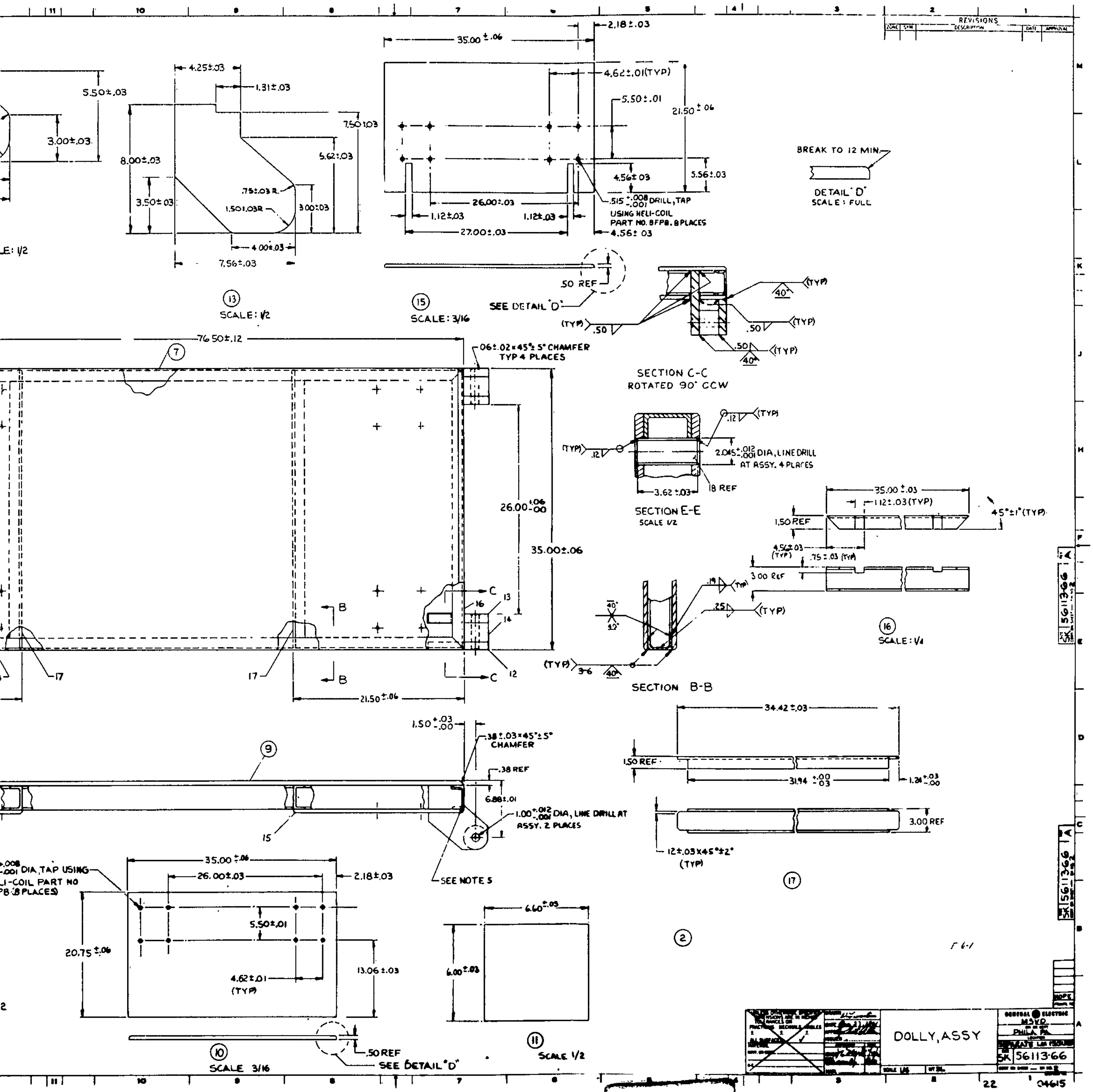
2

Figure 6-1. Dolly Assembly



SCALE: 1/2
SCALE: 1/2
SCALE: 3/16
SCALE: 1/2
SEE DETAIL "D"
SECTION C-C
ROTATED 90° CCW
SECTION E-E
SCALE 1/2
SECTION B-B
SEE DETAIL "A"
.515 +.008 -.001 DRILL, TAP USING HELI-COIL PART NO. 8FPB, 8 PLACES
.06±.02×45°±.5° CHAMFER TYP 4 PLACES
.38±.03×45°±5° CHAMFER
1.00 +.012 -.001 DIA, LINE DRILL AT ASSY. 2 PLACES
SEE NOTE 5
.515 +.008 -.001 DIA, TAP USING HELI-COIL PART NO 8FPB (8 PLACES)
DETAIL "A"
SCALE 1/2
SCALE 1/2
SCALE 3/16
SEE DETAIL "D"
SCALE 1/2

1



2

Figure 6-1. Dolly Assembly (Cont'd)

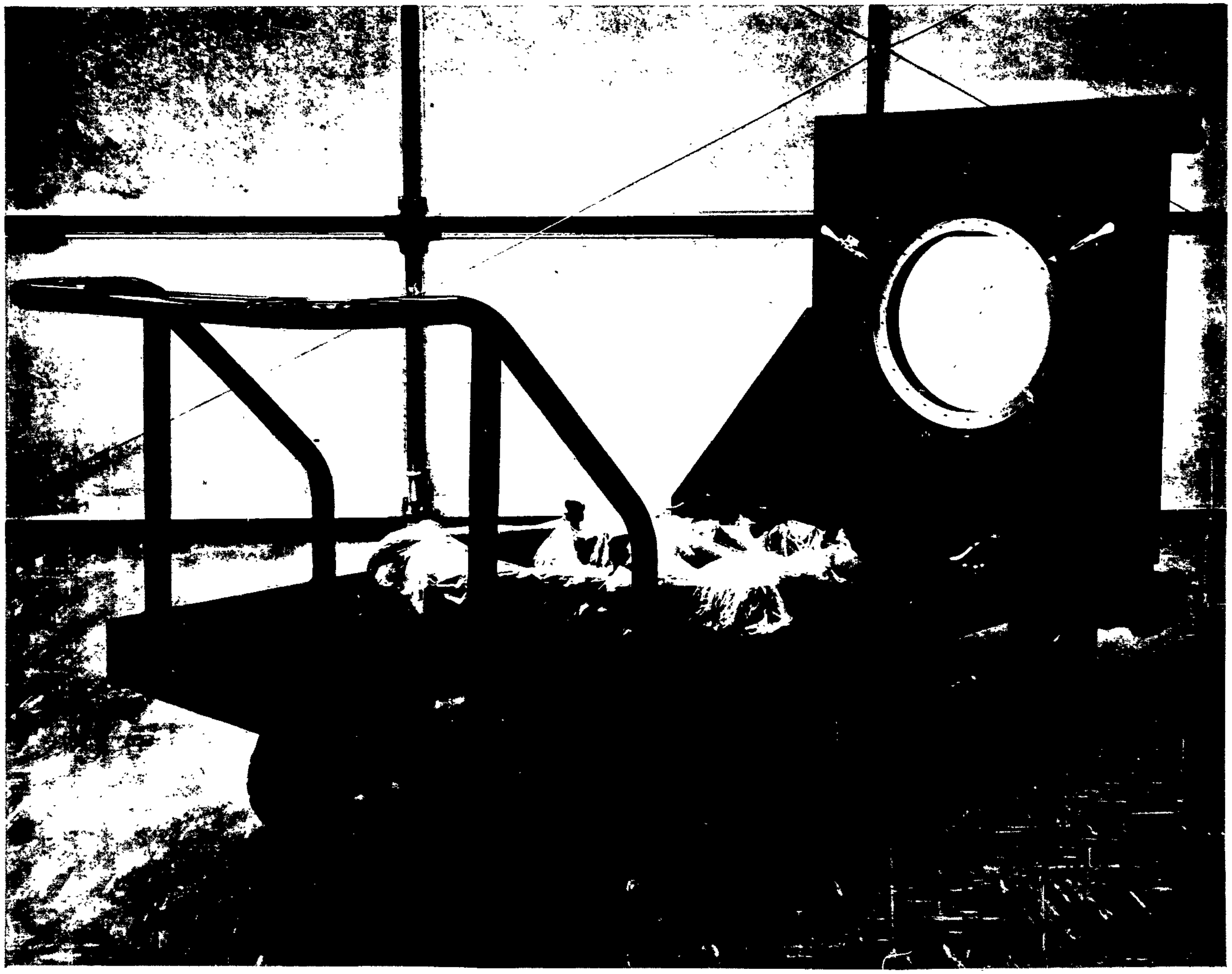


Figure 6-2. Bearing Housing Assembly (Front View)

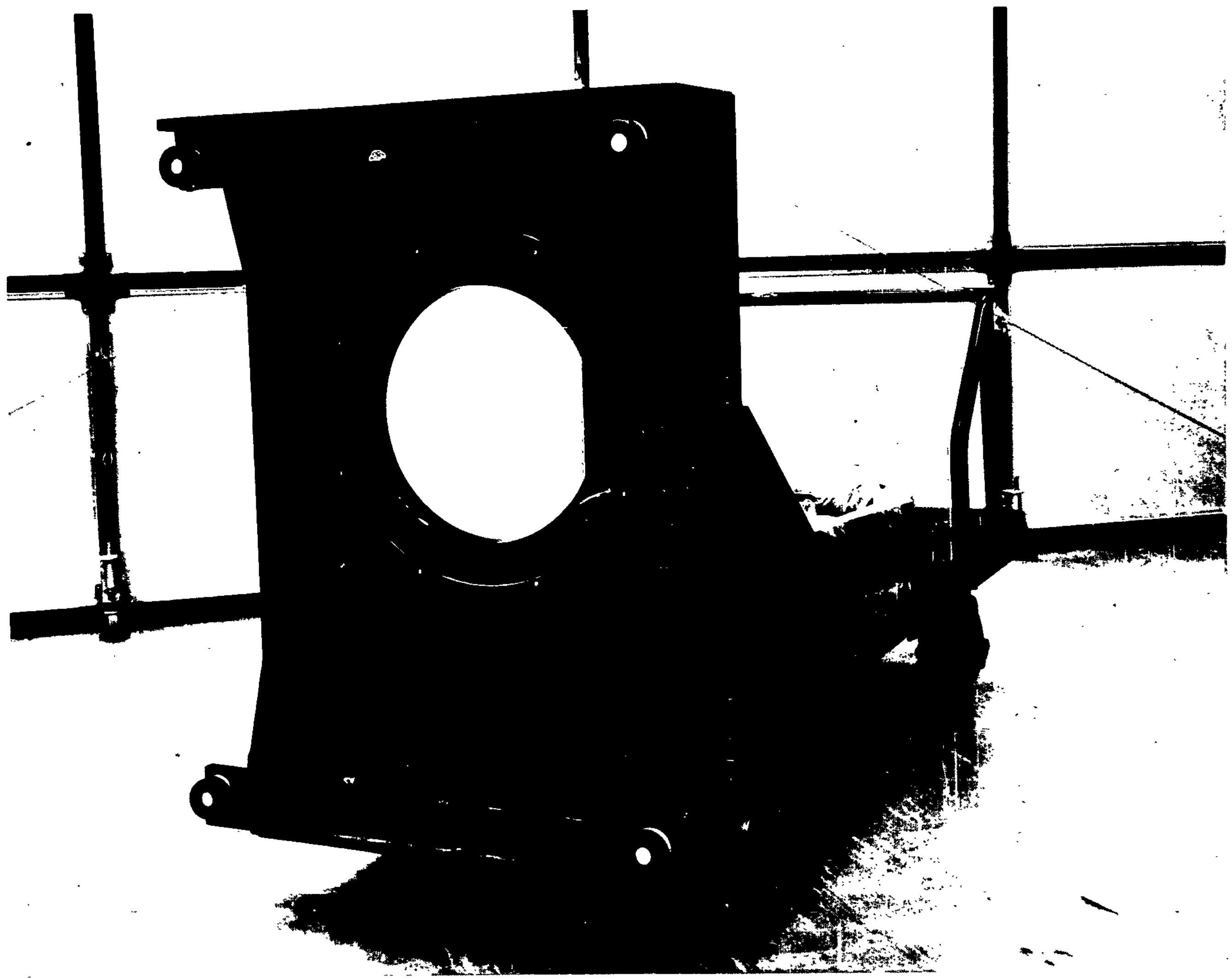


Figure 6-3. Bearing Housing Assembly (Rear View)

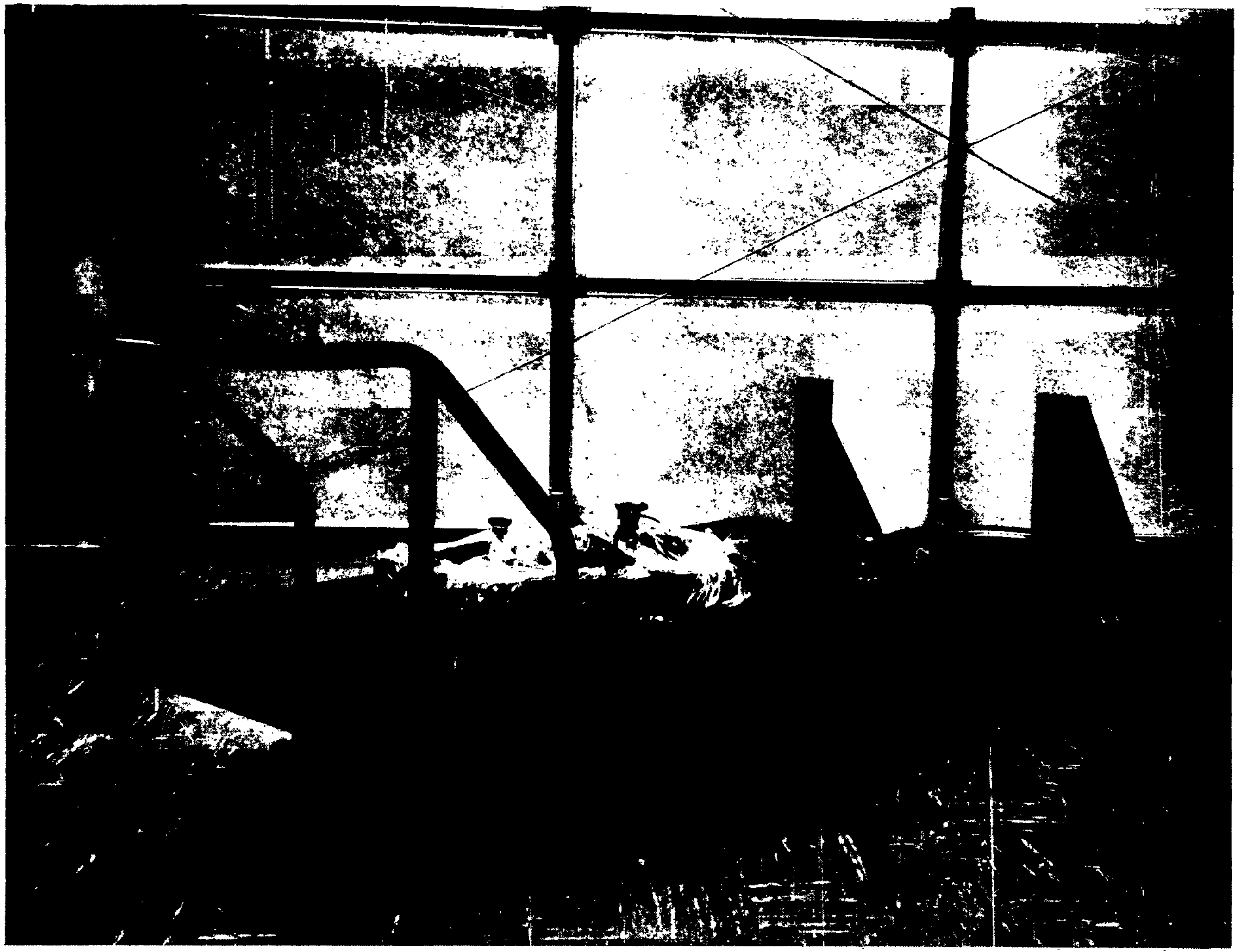


Figure 6-4. Bearing Housing Assembly

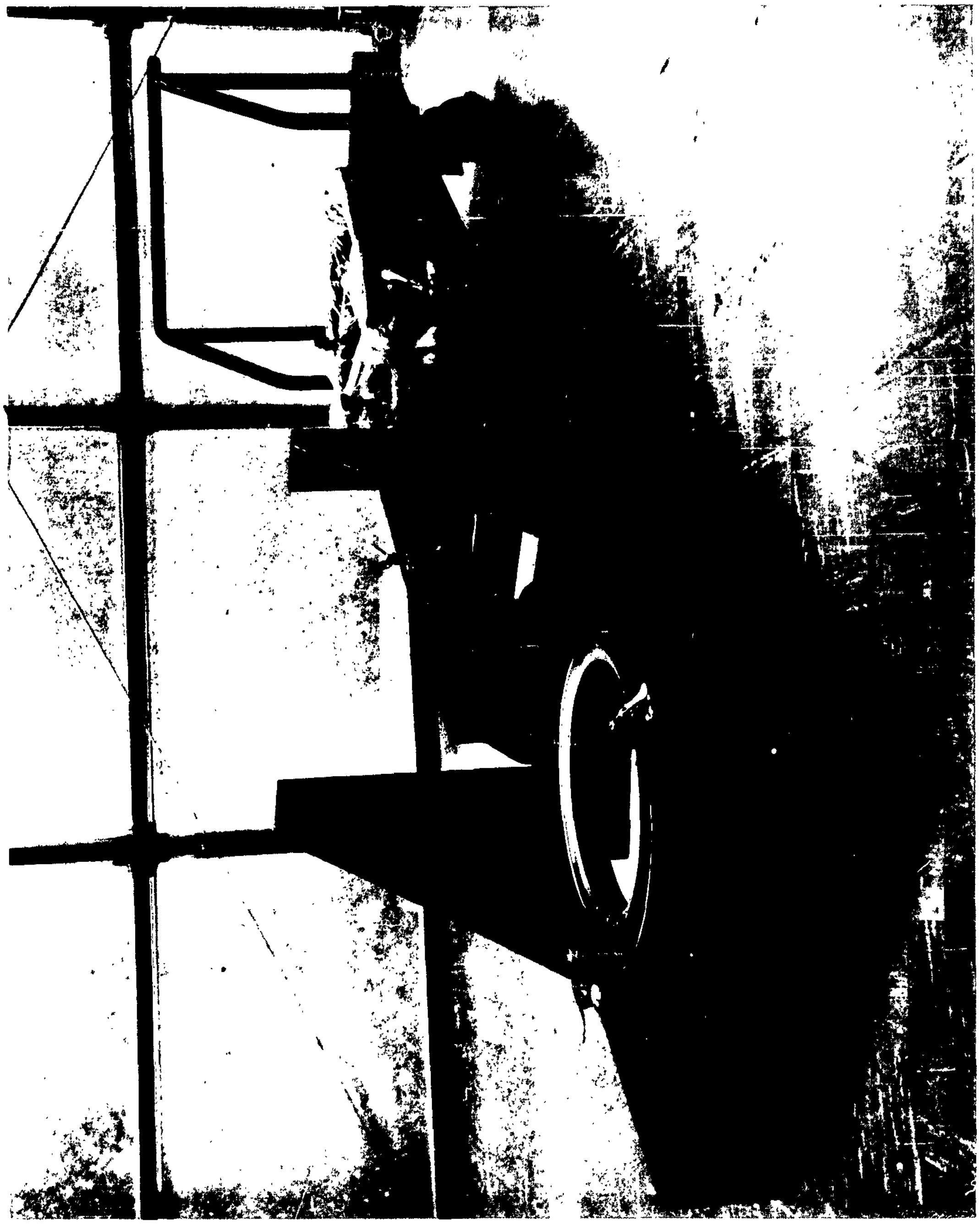
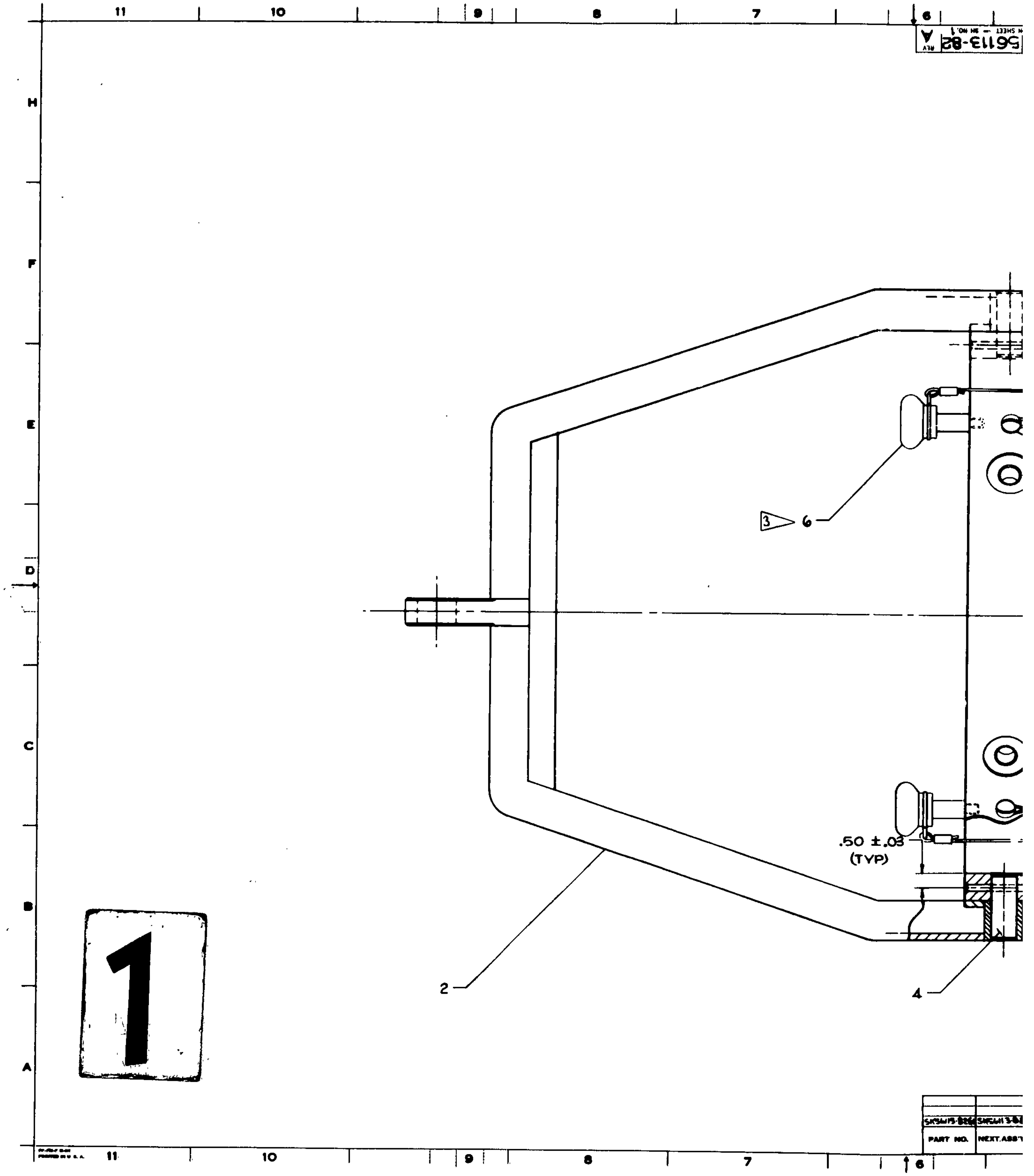


Figure 6-5. Bearing Housing Assembly



56113-82
REV A
.50 ±.03
(TYP)
3
6
2
4
PART NO.
NEXT ASS'Y
1

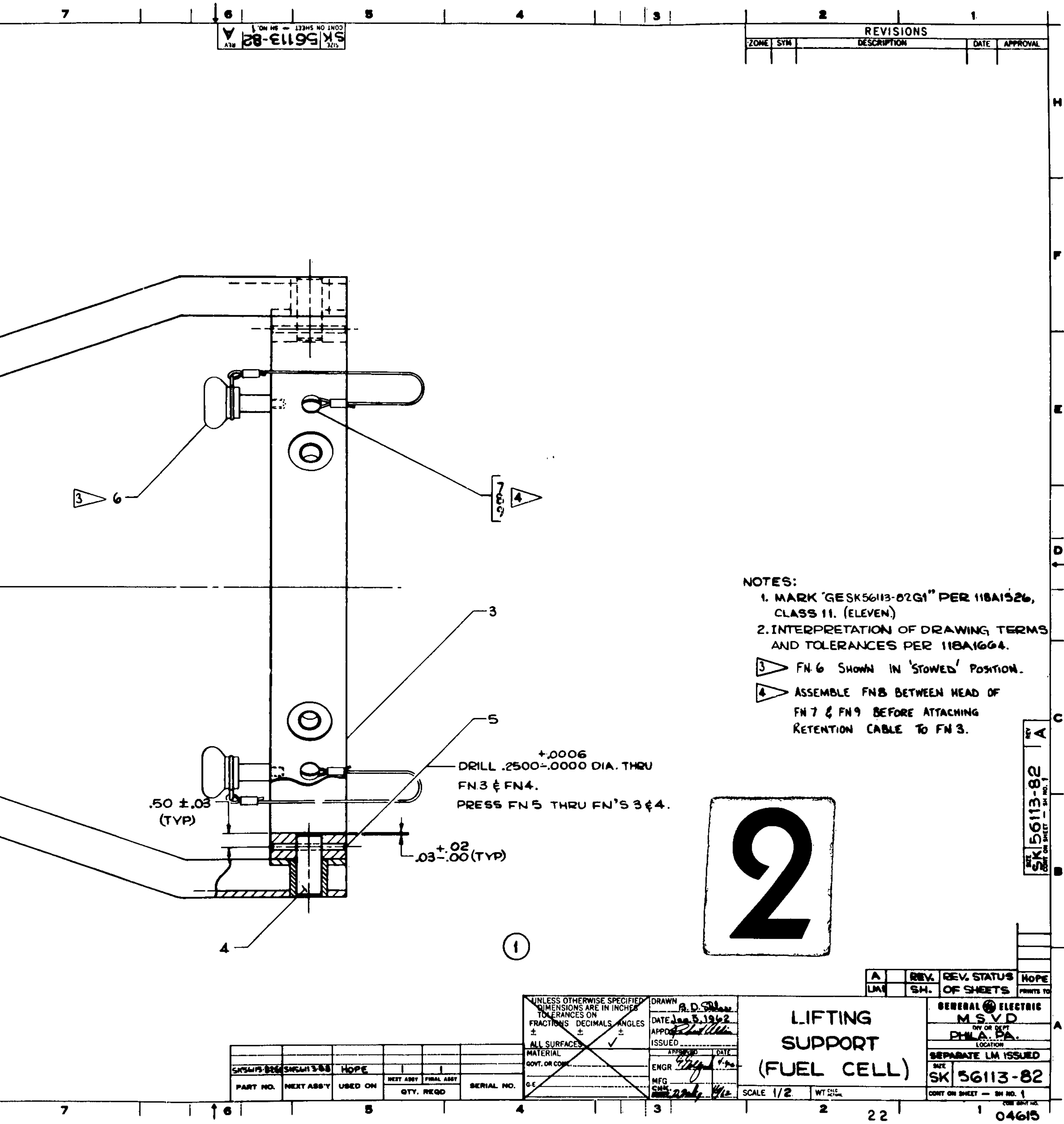


Figure 6-6. Lifting Support (Fuel Cell)

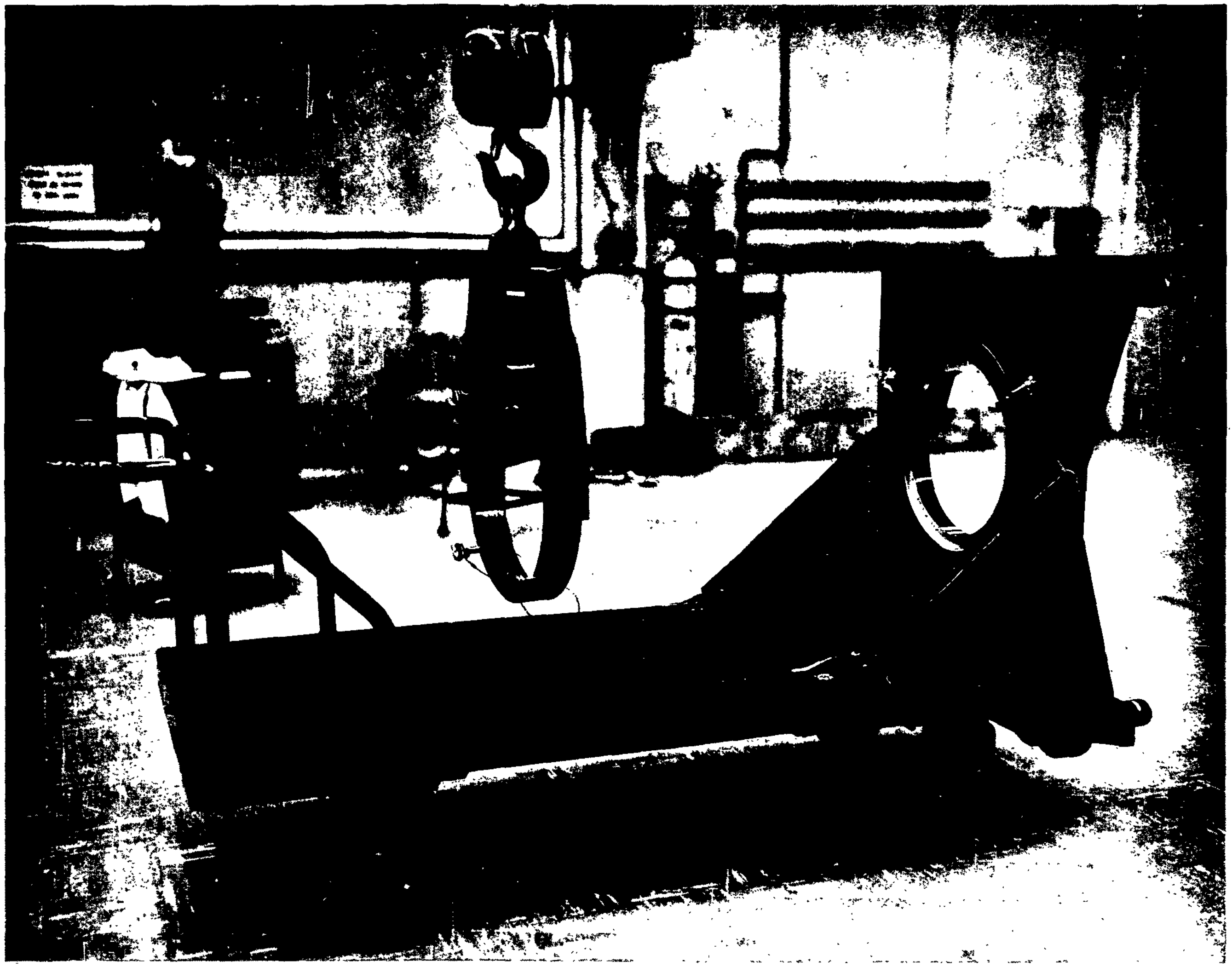


Figure 6-7. Attitude of Lifting and Support Assembly When Used in Conjunction With Dolly Assembly

Figure 6-8. Attitude of Lifting and Support Assembly When Used in Conjunction With Dolly Assembly

hydrogen and oxygen compressors, Figure 6-10, are actuated. The compressors draw gas from the supply bottles, compress it and force it into the fuel tanks. A nitrogen system which utilizes pre-purified (99.998%) nitrogen was incorporated so that it could be attached to either the oxygen or hydrogen systems via quick disconnects for purging or decontaminating either system. Vacuum pumps and tanks were then incorporated inthe fuel systems, which would (1) generate spacecraft regulator reference vacuum; (2) scavenge fuel cell operational purge gases, and (3) evacuate gases from the fuel systems during purging or decontamination operations. The design of this system, Figure 6-11, was carried to a point whereby material could be ordered and fabrication performed. Changes in system requirements were anticipated; therefore, the drawings were frozen and changes were to be incorporated after the unit was completely assemblied. Figures 6-12 and 6-13 are photographs of the pneumatic service package during assembly. As assembly proceeded, system requirements changed and they were incorporated into the assembly without incident. The latest schematic of the system is shown by Figure 6-14 . Contract termination occurred with the pneumatic service package 90% complete and formal drawings not revised to present design.

Abbreviations pertinent to Figure 6-14 are as follows:

HMSV	Hydrogen Main Shut-Off Valve
HCBPV	Hydrogen Compressor By-Pass Valve
HCSV	Hydrogen Compressor Shut-Off Valve
HTDV	Hydrogen Tank Dump Valve
HTVV	Hydrogen Tank Vacuum Valve
HVTBV	Hydrogen Vacuum Tank Bleed Valve
HVPSV	Hydrogen Vacuum Purge Shut-Off Valve
HBV	Hydrogen Bottle Valve
HFQD	Hydrogen Fueling Quick Disconnect
HVPQD	Hydrogen Vacuum and Purge Quick Disconnect
NMSV	Nitrogen Main Shut-Off Valve
NBV	Nitrogen Bottle Valve
O (above)	Oxygen (Same as Hydrogen)
HCAV	Hydrogen Compressor Air Operating Valve (also 0_2)
CAQD	Compressor Air Quick Disconnect
HCRV	Hydrogen Compressor Air Regulator Valve (also 0_2)

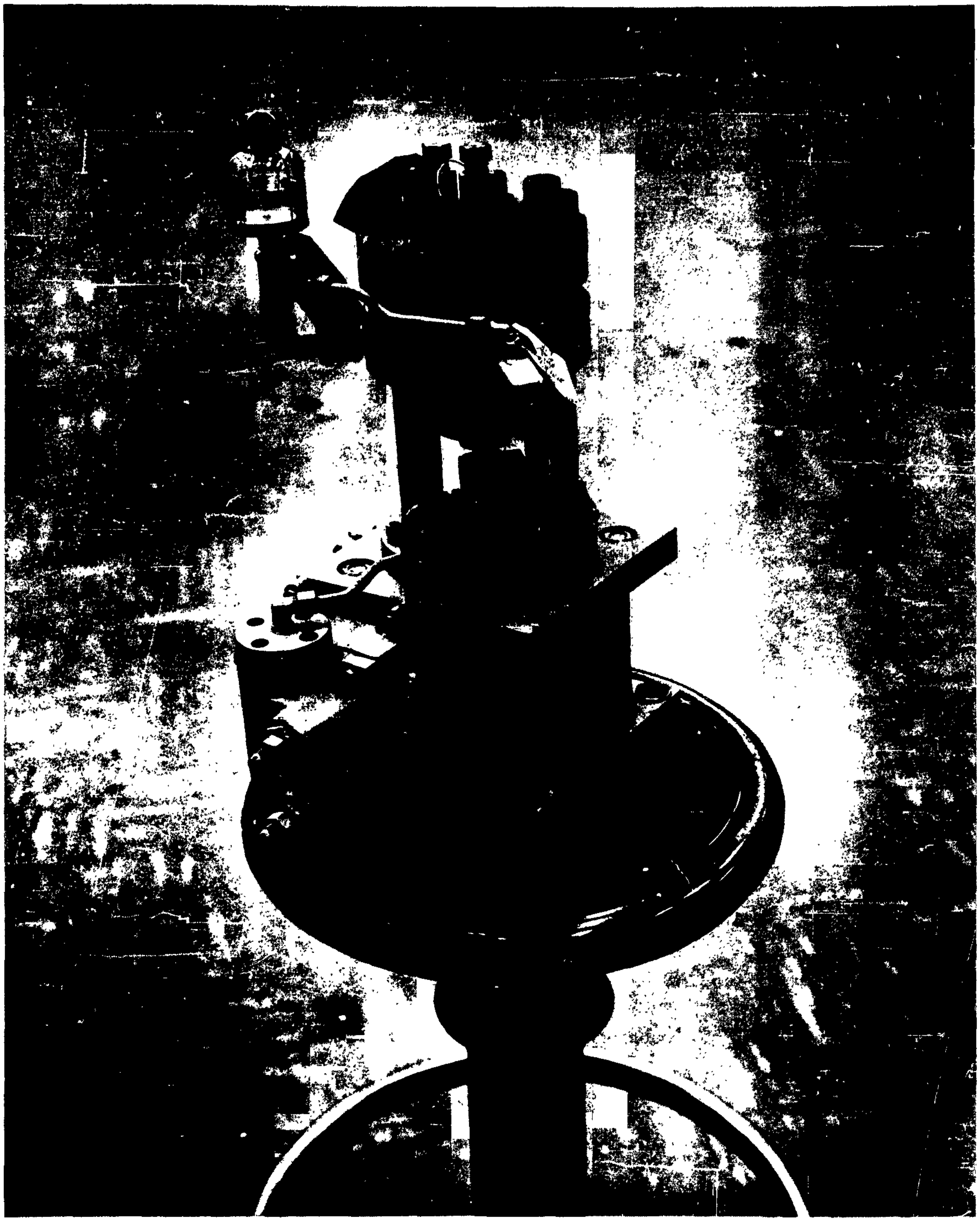


Figure 6-10. Hydrogen and Oxygen Compressors

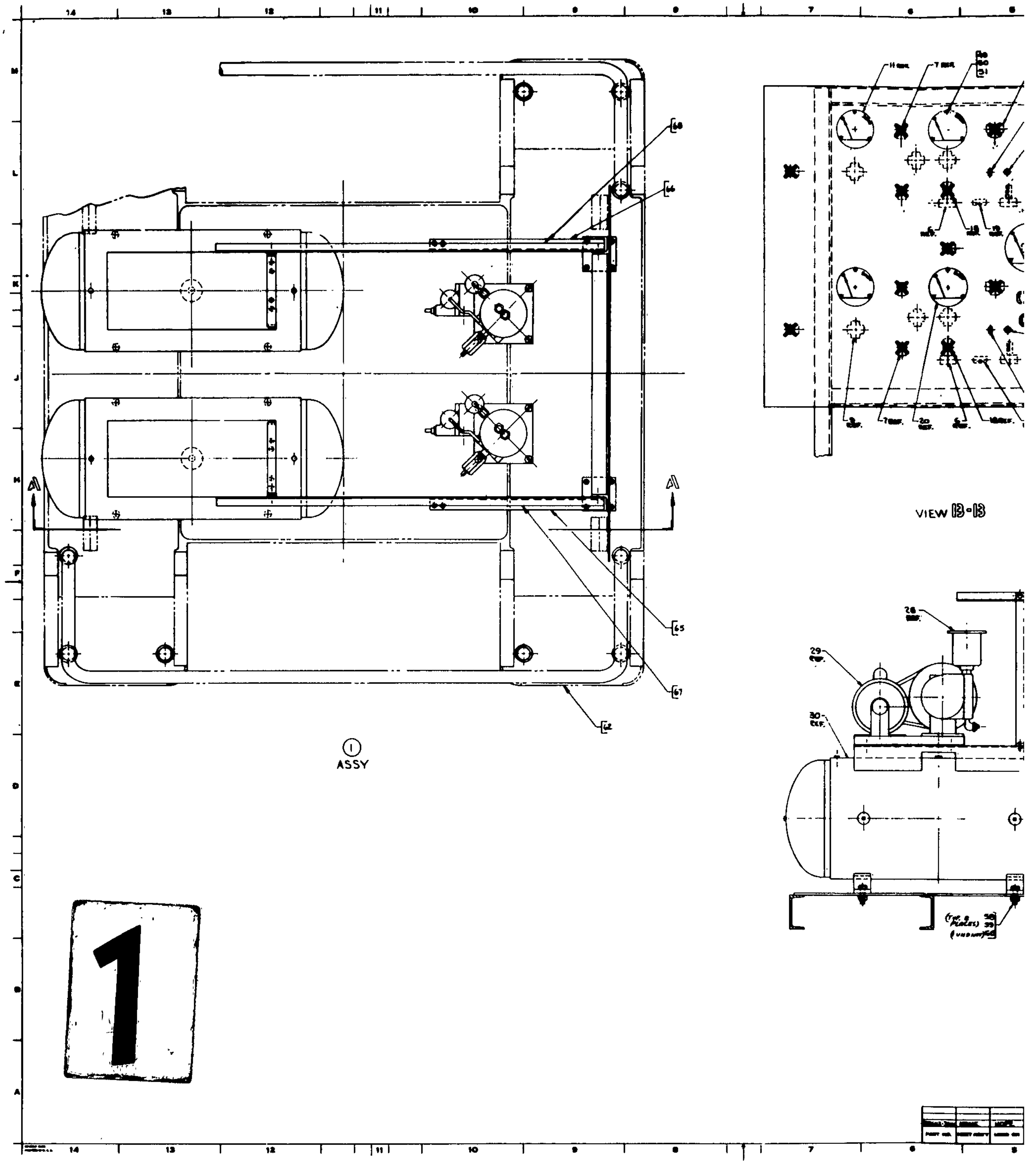


Figure 6

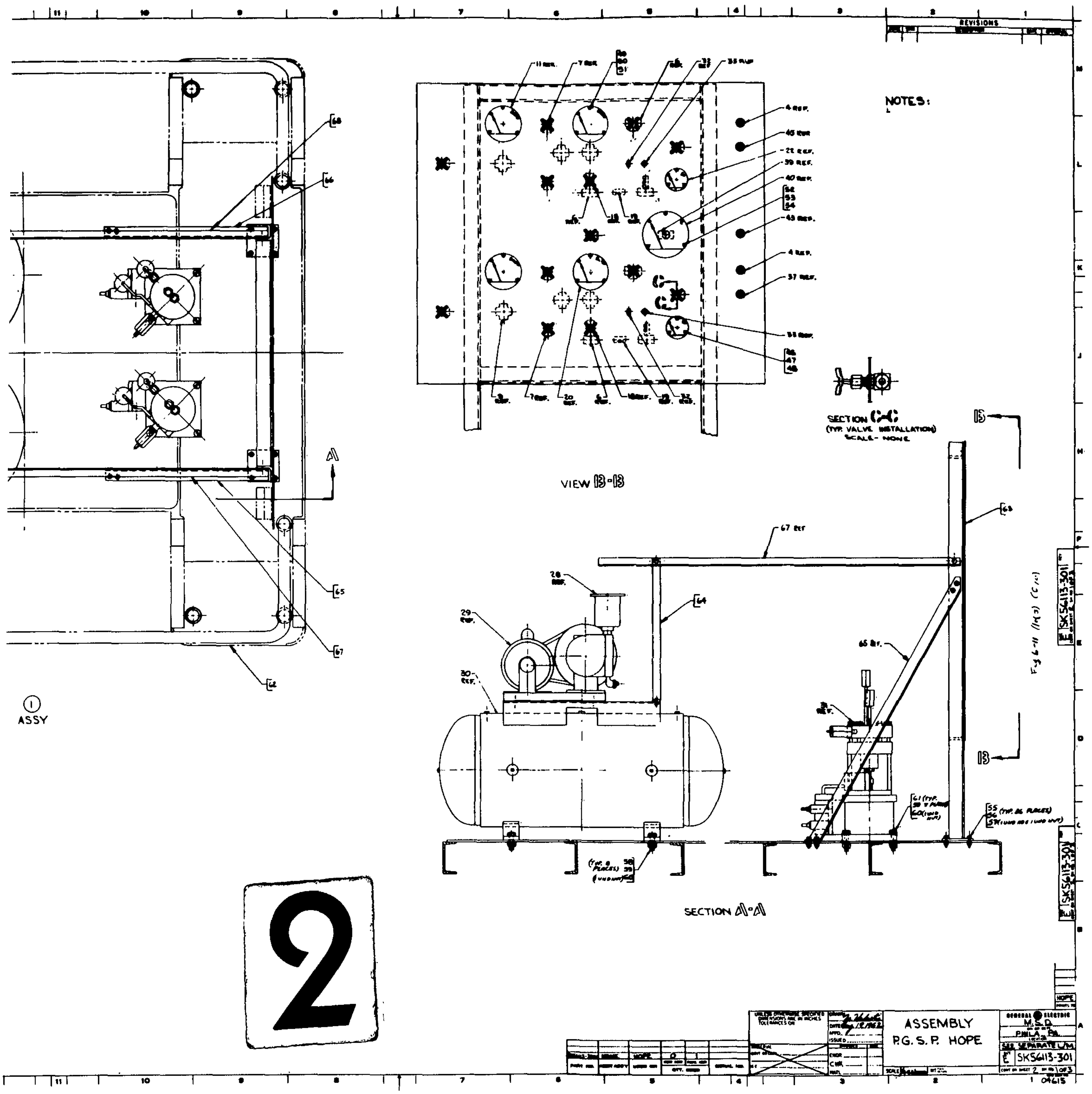


Figure 6-11. Assembly, P.G.S.P. HOPE (Schematic)

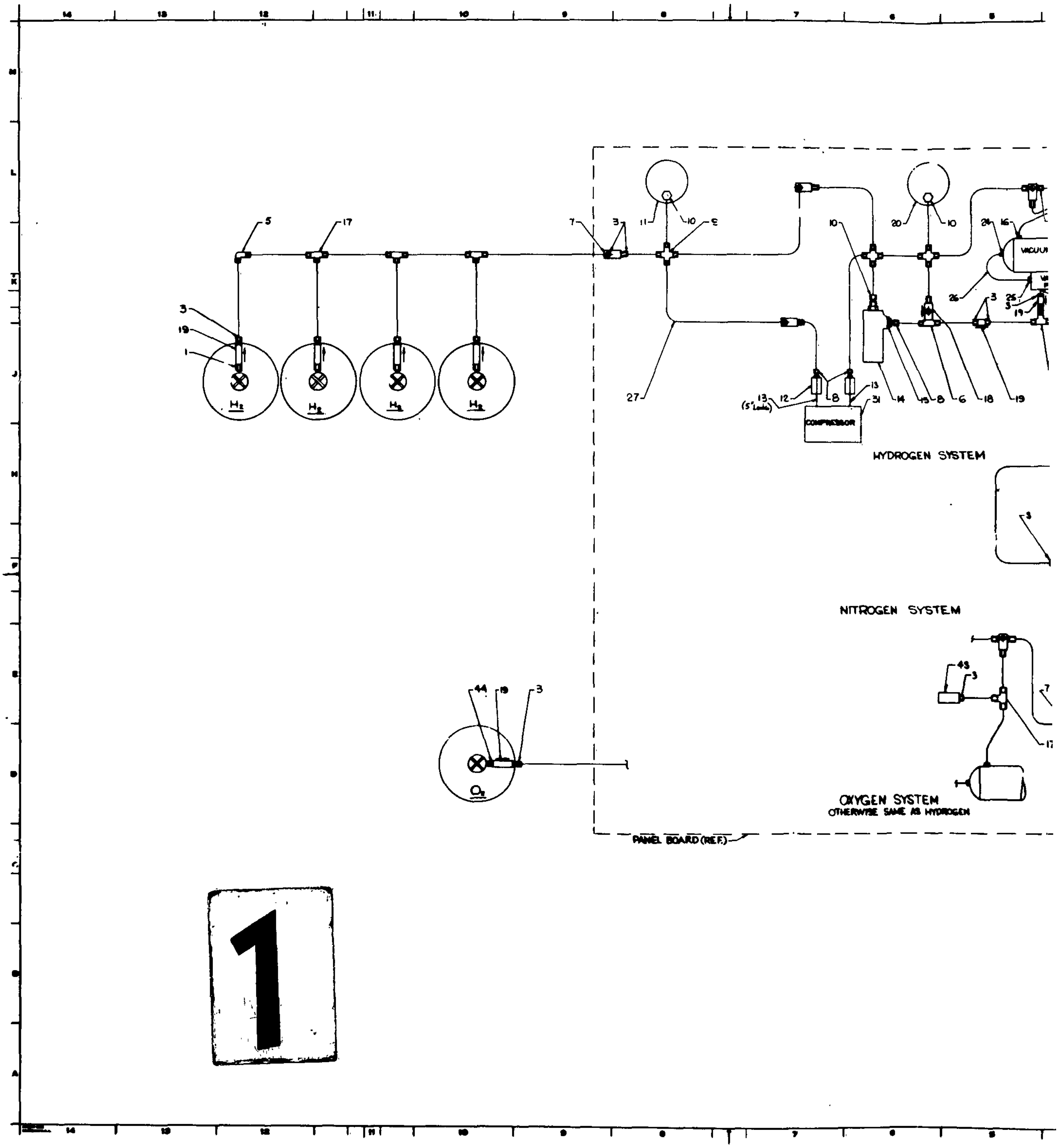


Figure 6-11. Assemb

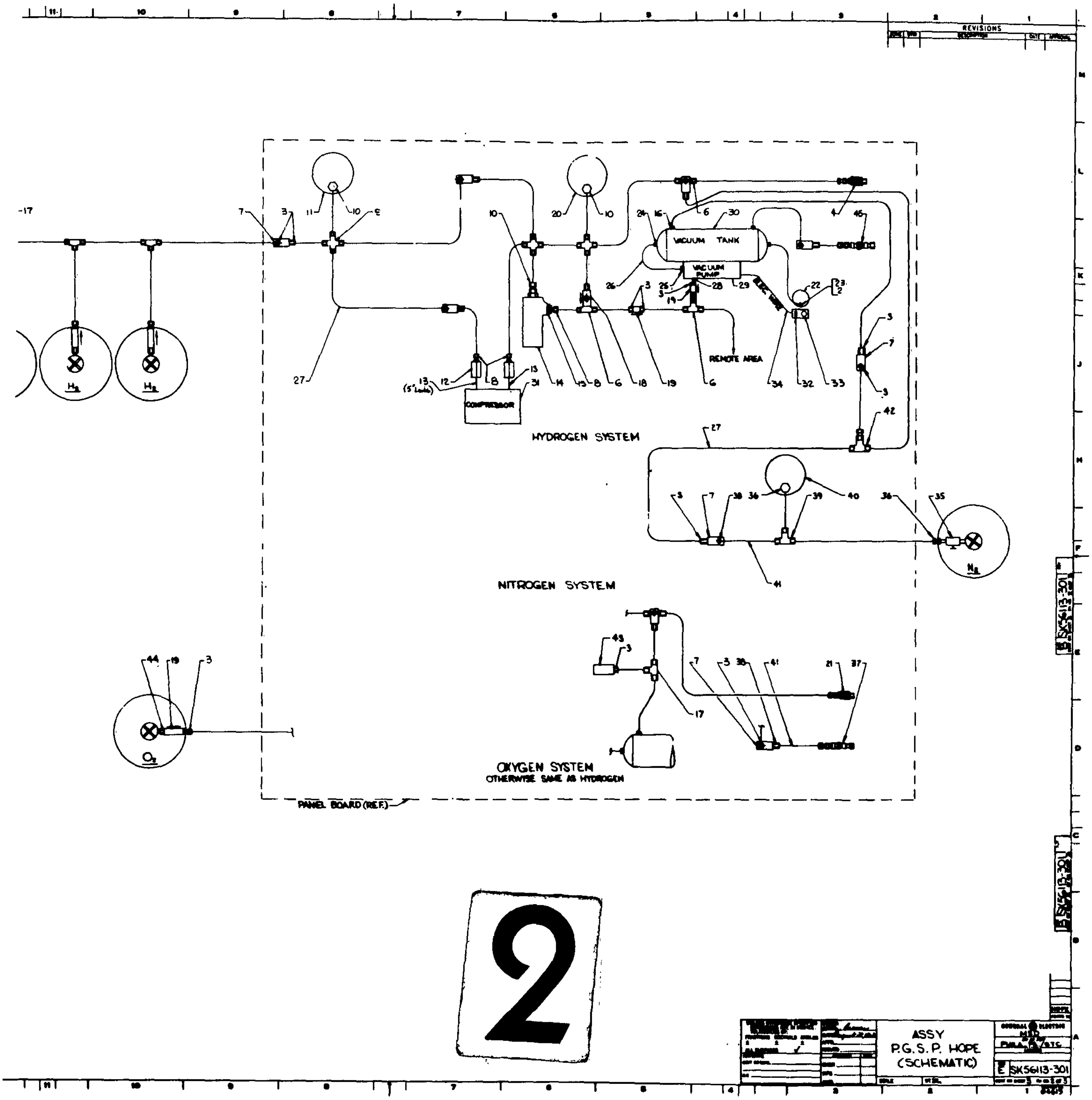


Figure 6-11. Assembly, P.G.S.P. HOPE (Schematic) (Cont'd)

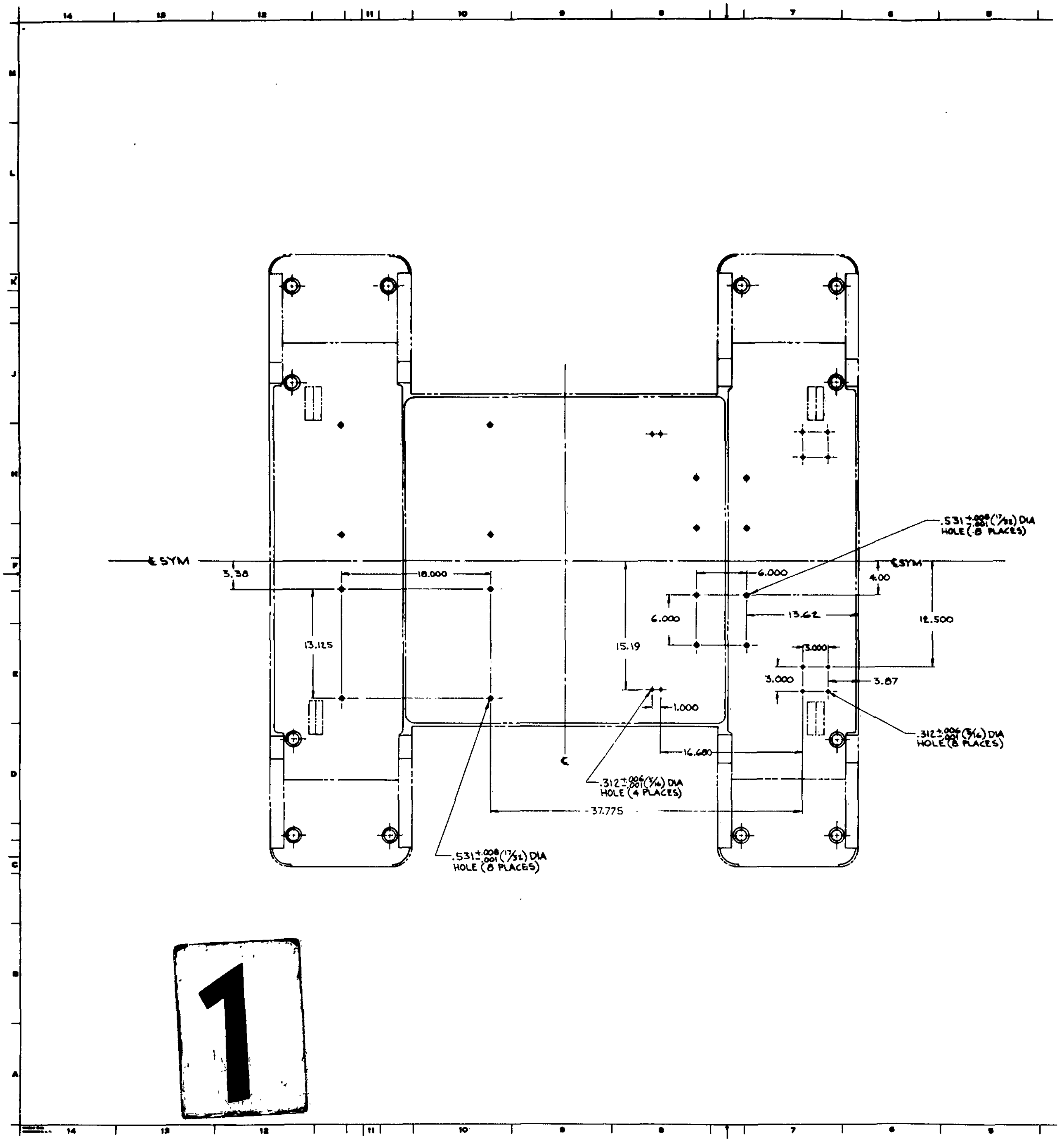


Figure 6-11. Assemb

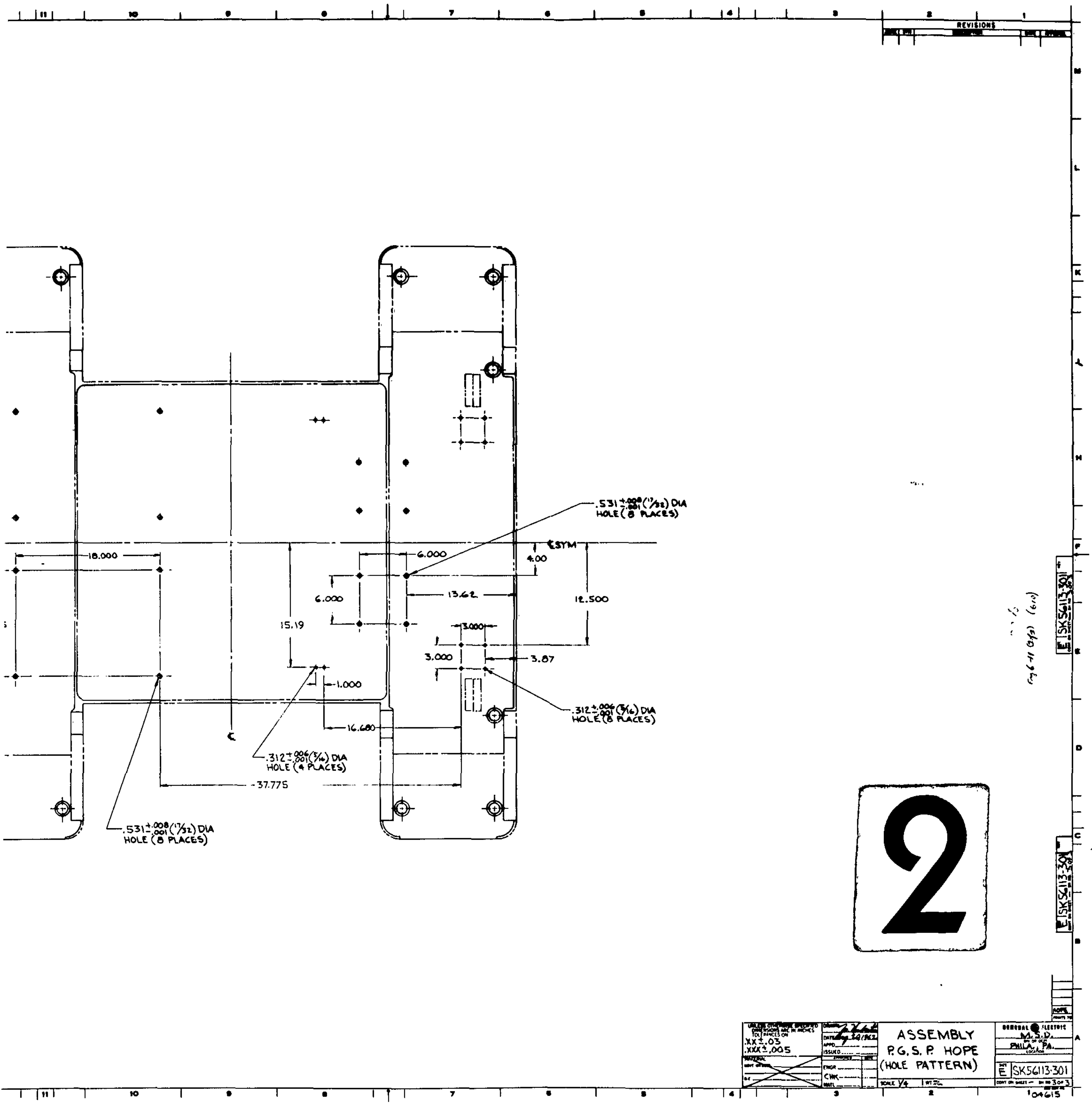


Figure 6-11. Assembly, P.G.S.P. HOPE (Schematic) (Cont'd)

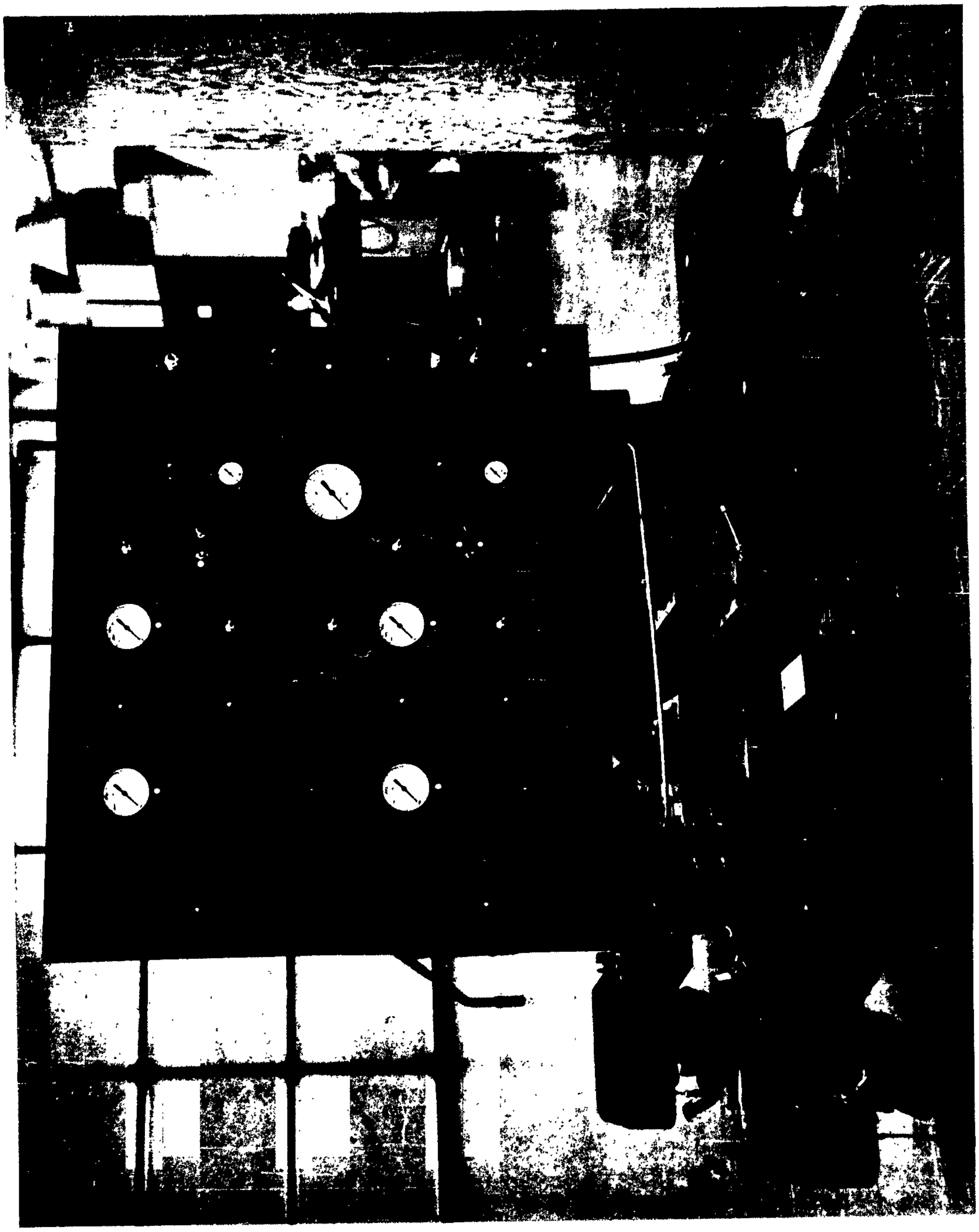


Figure 6-12. Pneumatic Service Package During Assembly

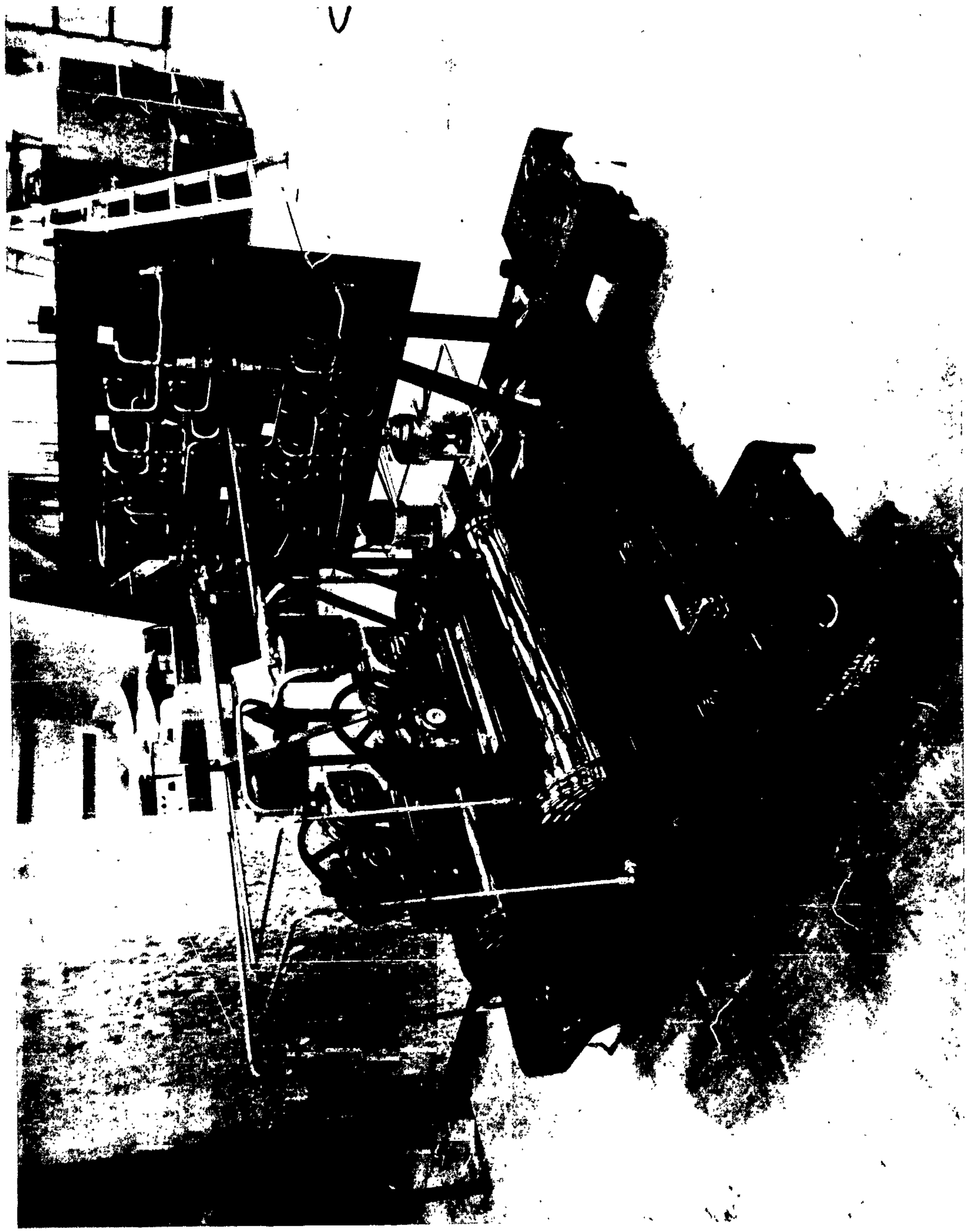


Figure 6-13. Pneumatic Service Package During Assembly

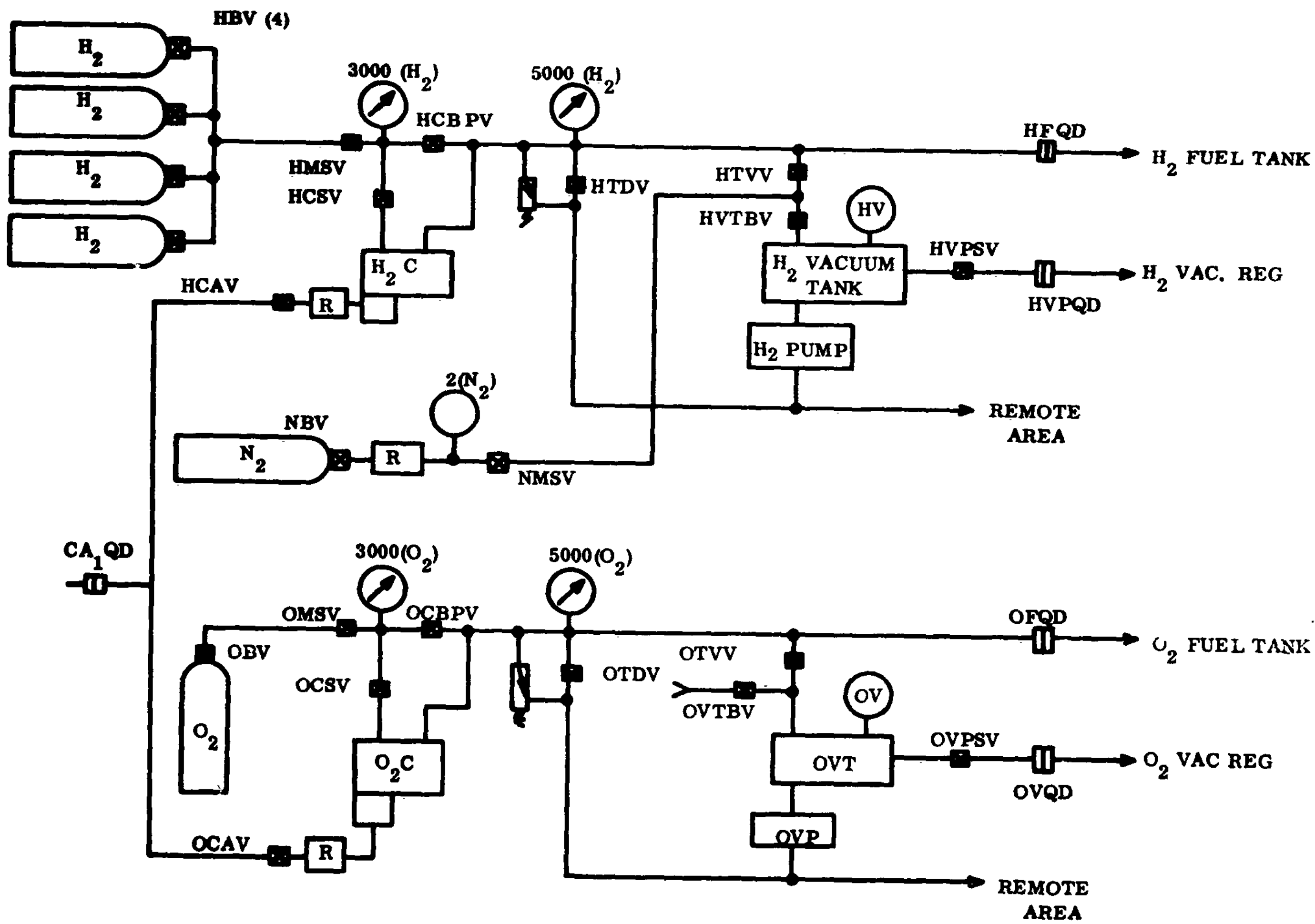


Figure 6-14. Pneumatic Ground Service Package Schematic

SECTION 7

SYSTEM TESTING

R. Barchet
M. Read

7.0 SYSTEM TESTING

7.1 GENERAL

This section of the report describes accomplishments relating to system testing of the HOPE development test vehicle (DTV).

During this period, major effort has been directed toward three phases of the system testing program. These are the Seven-Day Bench Test, Thermal/Vacuum Test, and Fuel Cell Subsystem Acceptance Tests.

7.1.1 Overall Test Plan

The Phase Ia HOPE Program was essentially a testing program to establish the performance of the experiment portion of the HOPE spacecraft. The following system tests were planned:

TEST	SCHEDULED DATE
Seven-Day Bench Test	November 5 - November 16
Seven-Day Thermal/Vacuum Test	November 26 - December 7
Proof Pressure and Leakage Tests	December 10 - December 12
Shock Tests	December 12 - December 14
Acceleration	December 17 - December 21
Vibration	January 2 - January 4
Proof Pressure and Leakage	January 7 - January 11
Seven-Day Bench Test	January 21 - February 1

7.2 SEVEN-DAY BENCH TEST

A General Test Plan for the Seven-Day Bench Test was issued, reviewed, and approved by ASD. In addition, a detailed test plan for the Seven-Day Bench Test was issued. Portions of the detailed test plan are included below.

7.2.1 Objectives of Seven-Day Bench Test

The primary objective of this test was to establish the capability of the fuel cell, fuel supply and fuel control subsystem to function as an integrated space power system.

7.2.2 Test Setup

During the Seven-Day Bench Test the DTV was to be operated in a high pressure safety area. All instrumentation, the pneumatic ground service package (PGSP) and test operators were to be located outside of the test room. The test would have been conducted with the HOPE spacecraft in a horizontal attitude containing:

- Hydrogen and oxygen gas storage tanks.
- Complete pneumatics subsystem.
- Complete fuel supply subsystem.
- Two (2) 25-watt fuel cell modules.
- Two (2) fuel cell controllers, either flight type hardware or operating breadboards.
- Associated electrical harnessing and instrumentation.

In addition, fans would be provided to maintain air circulation and to cool the radiators.

If emergency dumping of the hydrogen storage tank was required, provisions were to be made for venting the gas outside of the building. Oxygen was to be dumped directly into the test room.

Capability for overriding the controllers and shutting down the fuel cells in case of emergency was also to be provided.

7.2.3 System Checkout

Prior to installation in the DTV, all components would have been individually checked out to verify satisfactory operation. However, in order to determine operating procedures and gain familiarity with system operation an extensive system checkout was required prior to the start of the Seven-Day Test. The following items were to be checked at this time:

- Leak Test of Pneumatic and Plumbing.
- Manual Control Overrides.
- Pneumatic Ground Service Package Checkout.
- Operational Check of Fuel Cell Module, Controller and Instrumentation at 15 psia.
- Operational Check with Modules at 30 psia.

7.2.4 Shutdown of Fuel Cell

Procedures for shutting down the fuel cell following testing or for safety reasons were also spelled out. These procedures were categorized into three areas:

Short Down-Time (8 hours or less with the unit attended)

For short down-times, such as between tests, it is only necessary to remove the controller and load from the module, keeping vacuum on the reference lines and consequently 15 psia pressure in the module.

Long Down-Time (over 8 hours, unit unattended)

If the unit is to be shut down for a long time, such as overnight, it would be necessary to vent both storage tanks to atmospheric pressure and flush the H_2 tank with nitrogen. This would prevent the module from building up uneven pressures internally due to consumption of H_2 and 0_2 during self-discharge at open circuit.

Emergency Shut Down

In emergencies such as fuel cell failure or a high rate leak it may be necessary to dump the fuel tanks and/or isolate one or more of the fuel cell modules. One module may be removed from service by closing the fuel control valves and carefully purging the unit until the unit is at essentially 0 psia internal pressure. If both modules are to be shut down, the fuel tanks could be dumped and the H_2 storage tank and hydrogen sides of the modules purged with nitrogen.

7.2.5 Seven-Day Bench Test Procedures

7.2.5.1 Test and Preparation

Before initiation of the Seven-Day Bench Test certain operations had to be performed and conditions established with regard to the operation of the fuel cell. These are:

- The water tank is packed with fresh absorbent and weighed.
- The gas storage tanks are pressurized to 2530 psig with operating gases.
- Vacuum is applied to the reference lines.
- The modules are purged until the open circuit voltage of each cell is 1.0 volts minimum.

7.2.5.2 Instrumentation and Controls

Instrumentation and controls required during the Seven-Day Bench Test are also described. The data to be obtained during testing is as follows:

- **Individual cell voltages**
- **Total module voltage**
- **Current to load**
- **H_2 and 0_2 storage pressure**
- **Module H_2 and 0_2 pressure**
- **Fuel cell internal temperature**
- **Purge occurrence**
- **External temperatures of fuel cell, vehicle, etc.**

7.2.5.3 Manual Controls and Overrides

Manual controls and overrides to be utilized during the test were as follows:

- Latch valve operation
- Purge valve operation
- Fuel cell controller override
- Load control
- Fill/Dump valve operation
- Module Δp control

7.2.6 Accomplishments - Instrumentation and Control Panel Assembly

The instrumentation and control panels required for the Seven-Day Bench Test were about 65% complete at termination. The control panels are shown in Figures 7-1 and 7-2 . Electrical schematics of the completed control circuits were prepared and are included with this report.

A ground command unit for the fuel cell electronic controller is shown in Figure 7-3 . The purpose of this unit is to manually reset the relays in the purge sequence should they fail to reset automatically.

Figure 7-4 is the schematic for manual operation of the fill/dump valves, including signal lights indicating when these valves are open.

A pressure differential override panel is shown in Figure 7-5. The purpose of this unit is to override purge valve operation and close the purge valves should the H_2 module pressure drop below safe limits during a purge. This could happen if the controller relays hung-up and did not open at the required time.

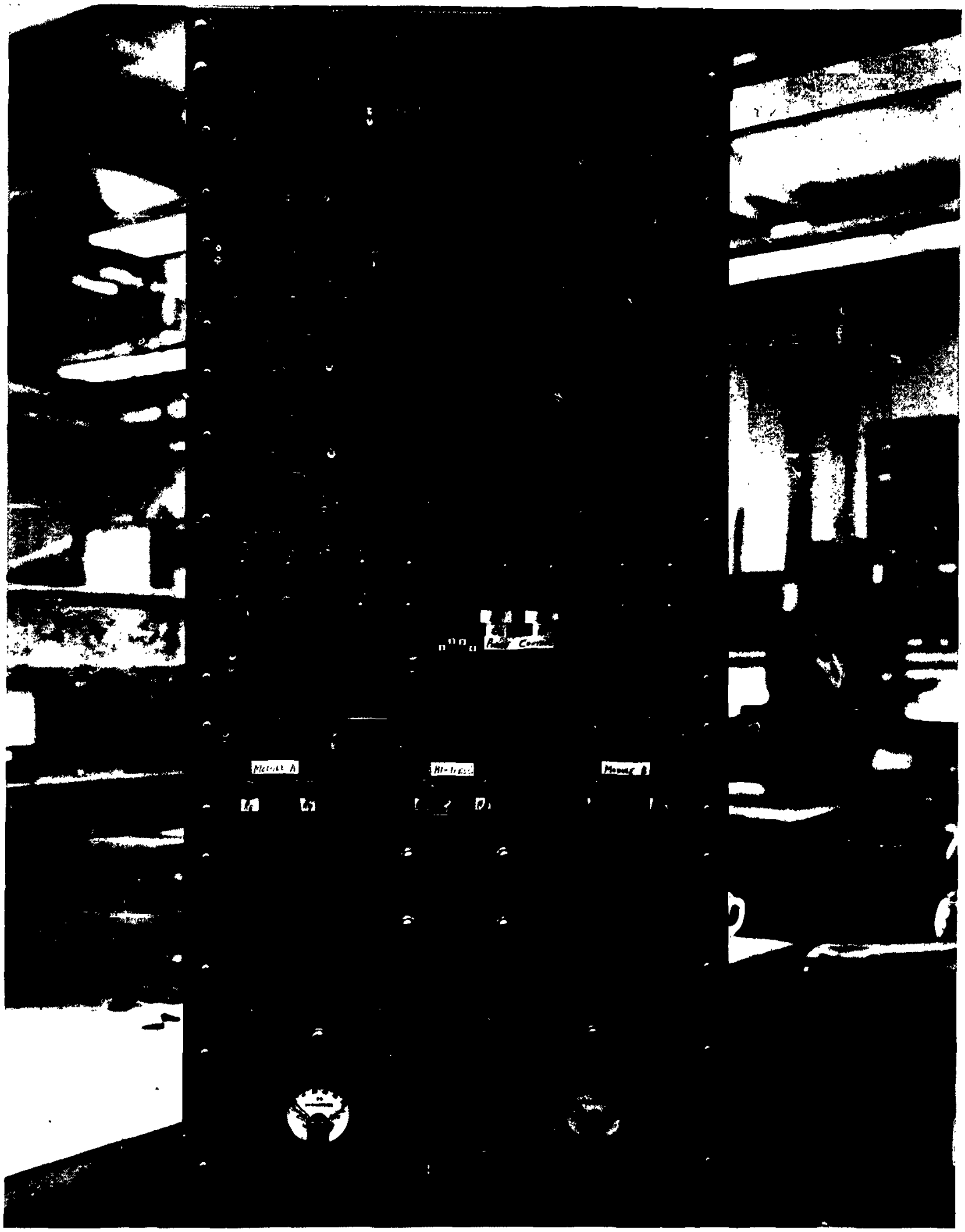


Figure 7-1. Control Panel

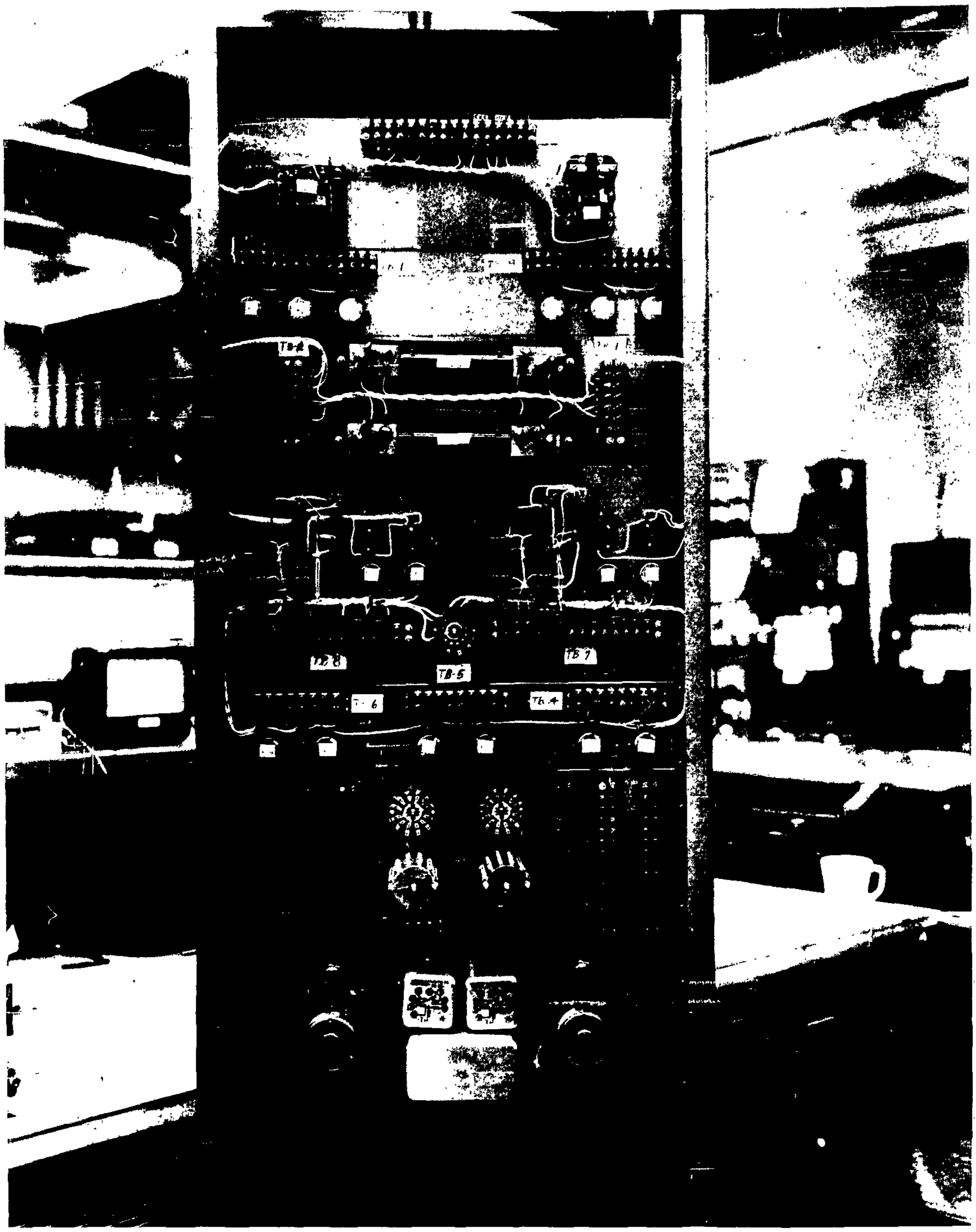


Figure 7-2. Control Panel

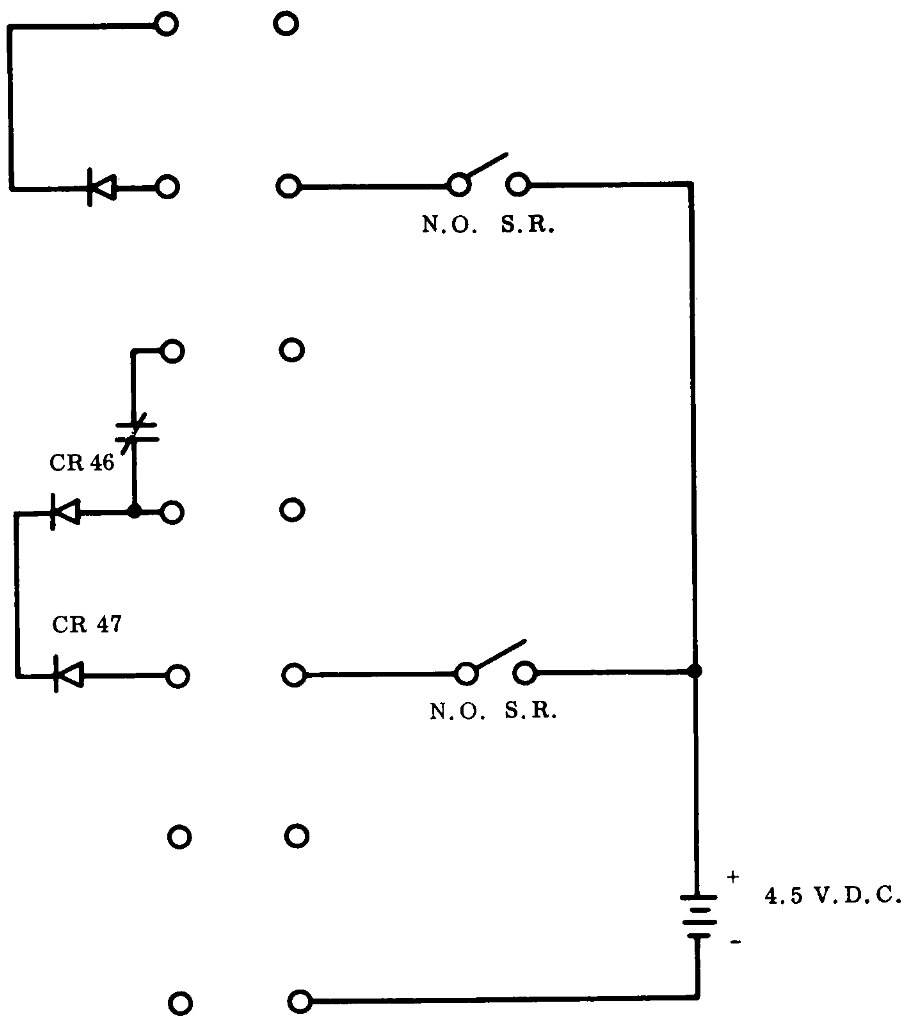


Figure 7-3. Controller Ground Command

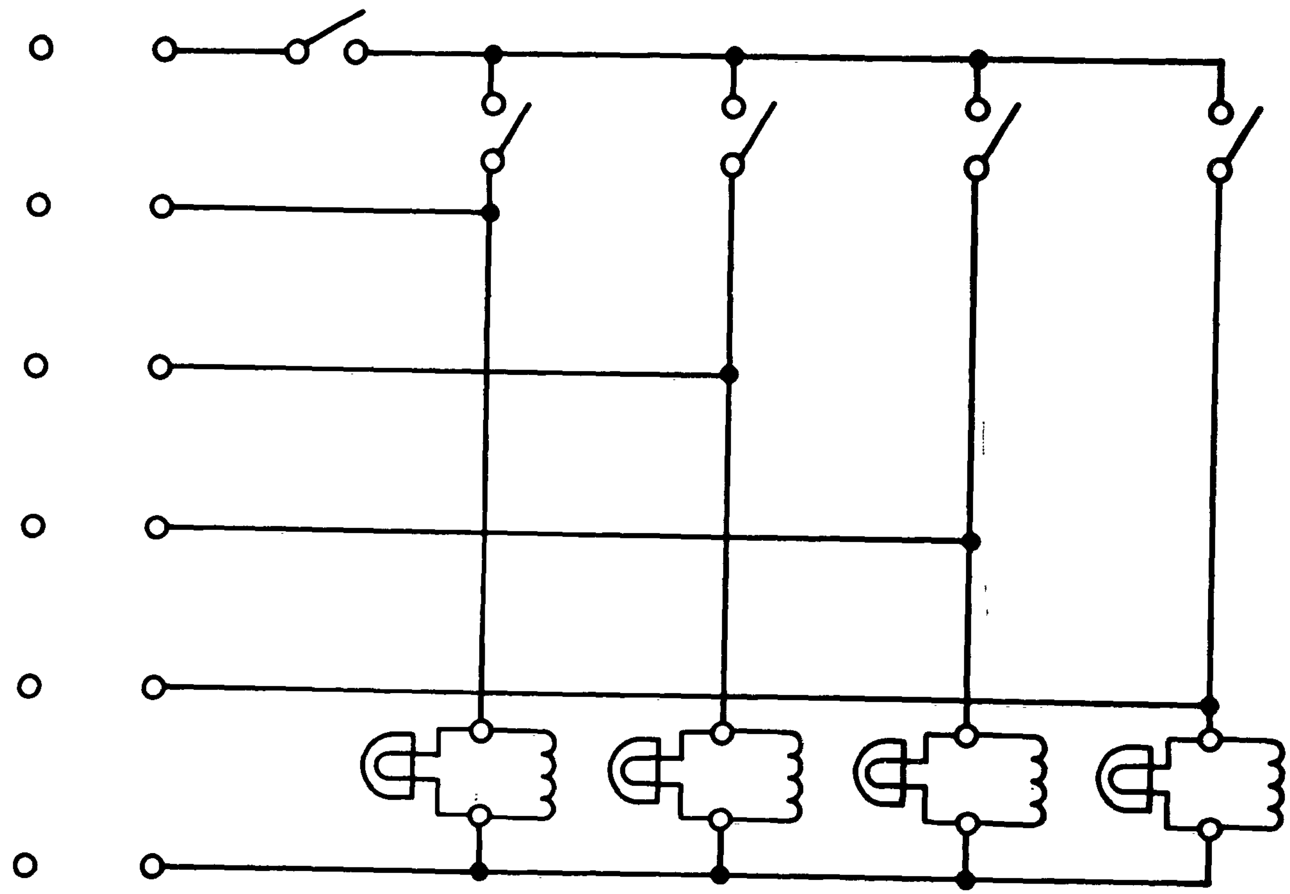


Figure 7-4. Fill-Dump Valve Panel

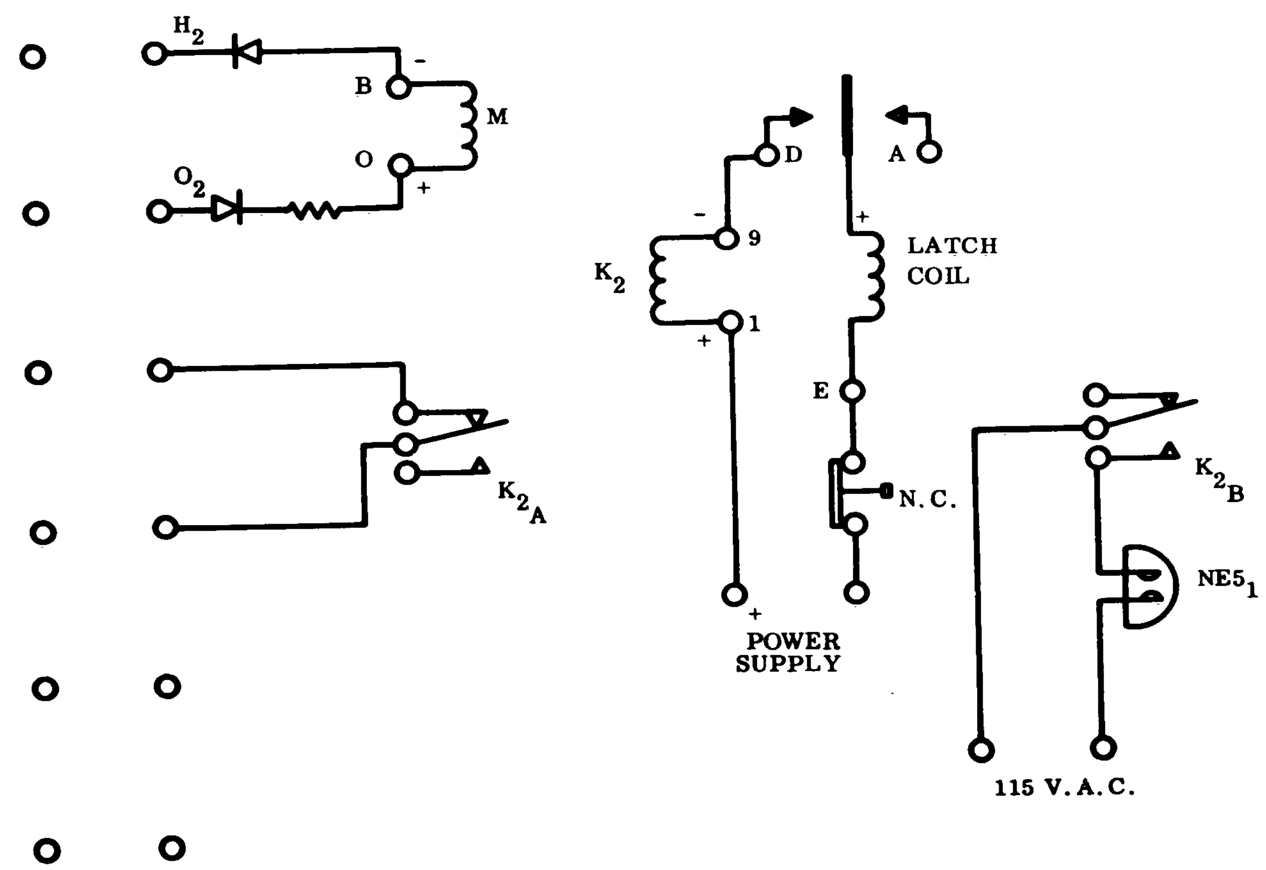


Figure 7-5. Pressure Differential Panel

Figure 7-6 is a schematic of the latch valve and purge control for one module. Included are manual controls for opening and closing the latch valves and a manual override to open the purge valve circuit and close the purge valve. The hook-up to the 30-volt recorder for noting purge occurrence as well as purge indication on the oscillograph are also shown.

Figure 7-7 is a diagram of the circuit used to initiate a manual purge. With this panel, H_2 and 0_2 may be purged separately or simultaneously. Included are adjustable timers for setting purge valve open times.

7.3 THERMAL/VACUUM TEST

A General Test Plan for the thermal/vacuum test was issued during this period.

The primary objective of this test was to establish the capability of the fuel cell, structure, fuel supply, pneumatics, and fuel controller subsystems to function as an integrated space power system when exposed to conditions simulating the thermal/vacuum environment of space. Up until this time the system, as designed for Phase Ia, will not have been operated as an integrated unit in the thermal/vacuum chamber.

Thermal simulation was to be accomplished by the use of DC heater blankets, stratigically placed to simulate the thermal load expected during orbit.

Instrumentation and data recording was to be accomplished with the equipment utilized for the bench test. Additional thermocouples were to be added, as required, to obtain an accurate temperature profile of the vehicle during the test.

7.3.1 Accomplishments

Thermal/vacuum test preliminary estimates were made for penetrations into the thermal/vacuum chamber. These included four gas lines (H_2 and 0_2 supply and H_2 and 0_2 purge vent lines) as well as electrical penetrations. The electrical penetrations consist of all control and instrumentation wires utilized in the Seven-Day Bench Test, plus heater and thermocouple wires required for thermal simulation and measurement during the thermal/vacuum test.

7.4 FUEL CELL SUBSYSTEM ACCEPTANCE TESTS

Acceptance tests for the fuel cell subsystem, including two (2) modules and one (1) water tank, were defined. These tests were divided into two (2) groups: Group 1 were tests to be performed by the fuel cell manufacturer, the Direct Energy Conversion Operation; and Group 2 were tests to be performed by the

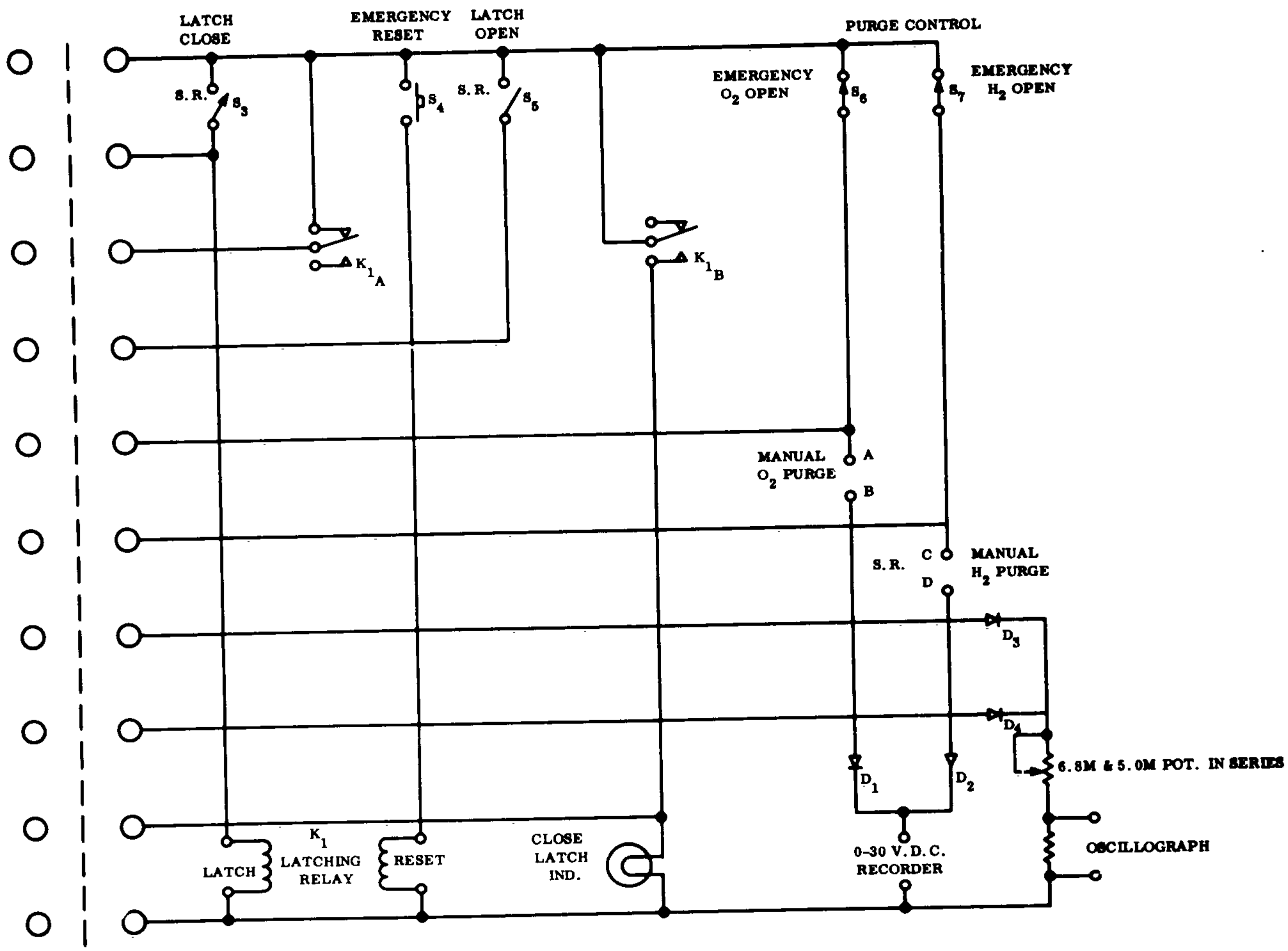


Figure 7-6. Latch-Purge Control

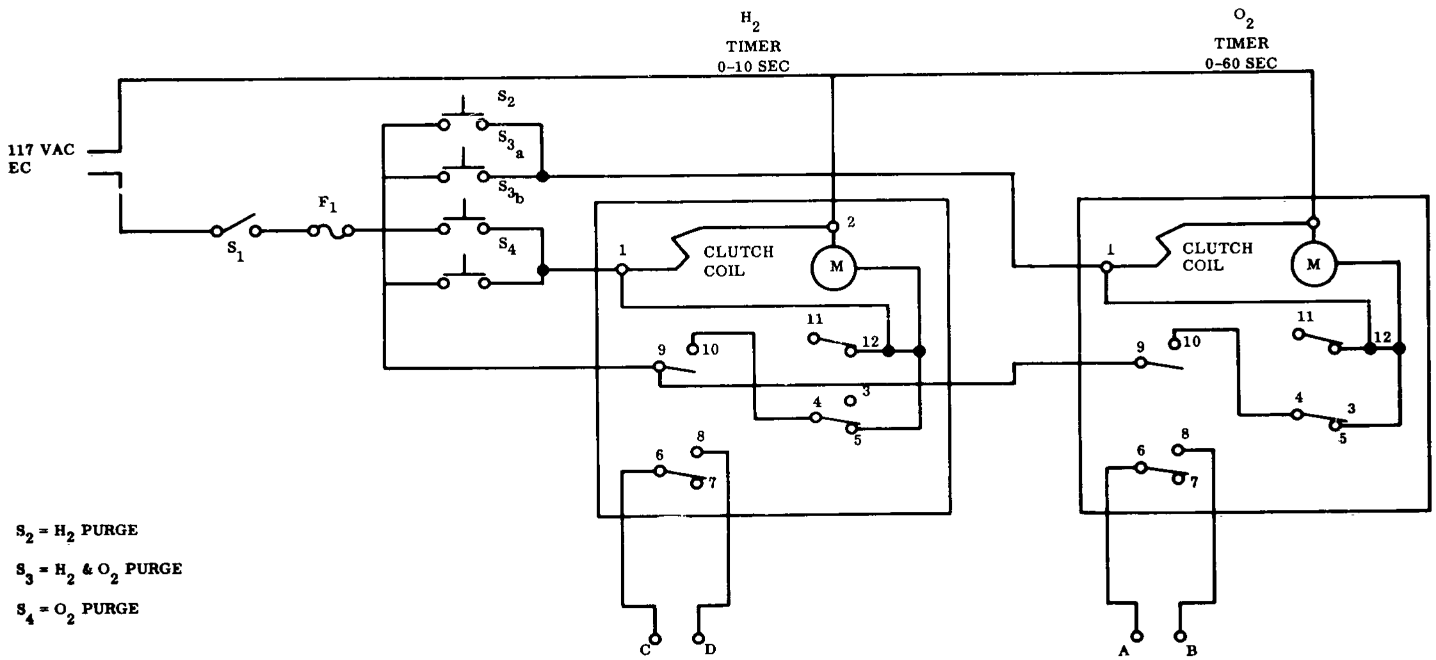


Figure 7-7. Manual Purge Panel

prime contractor, the Spacecraft Department of Missile and Space Division.

7.4.1 Group 1 - Acceptance Tests

The following tests were specified as the responsibility of the fuel cell manufacturer (DECO):

7.4.1.1 Performance Test

Each module must operate for 48 hours continuously at 25 watts and 28 volts, minimum.

7.4.1.2 Leak Test

Each subsystem will be leak tested at 45 psia. Leakage may not exceed 40 cc/2 hours for the subsystem or 10 cc/2 hours for each module and water tank compartment.

7.4.1.3 Thermistor Calibration

Before installation in the fuel cell module, the following tests should be performed on the thermistors. Each thermistor must be checked for no load resistance. In addition, thermistors should be calibrated with operating voltage across them in the temperature range of 140^{o}F to 180^{o}F.

7.4.2 Group 2 - Acceptance Tests

The following tests were specified as the responsibility of the Spacecraft Department, to be performed upon receipt of the fuel cell subsystem from DECO.

7.4.2.1 Thermistor Calibration

Complete thermistor calibration is to be performed over the temperature range of 35^{o}F to 140^{o}F with the thermistor installed in the module, and operating voltage across the thermistor.

7.4.2.2 Vibration Test

Each fuel cell module is to be vibration tested before acceptance by the Spacecraft Department. During vibration the unit shall be operated at a power level of 25 watts (28 volts minimum). Fuel cell performance and thermistor operation shall not be affected by the test.

7.4.2.3 Leak Test

Following vibration, each module will be leak tested as noted under paragraph 4.1.2. Leakage may not exceed 10 cc/2 hours per module at 45 psia.

7.4.3 Accomplishments

- Module Q-1 successfully passed the performance test, operating at better than 25 watts and over 28 volts continuously for 48 hours.
- Module Q-1 was leak-tested at 45 psia. No measurable leakage was detected.
- The water tank for the first DTV system was leak-tested at 45 psia. No measurable leakage was noted from either of the two compartments.

APPENDIX 1-A

PROPOSED PURGE METHOD FOR THE HOPE FUEL CELL

APPENDIX 1-A

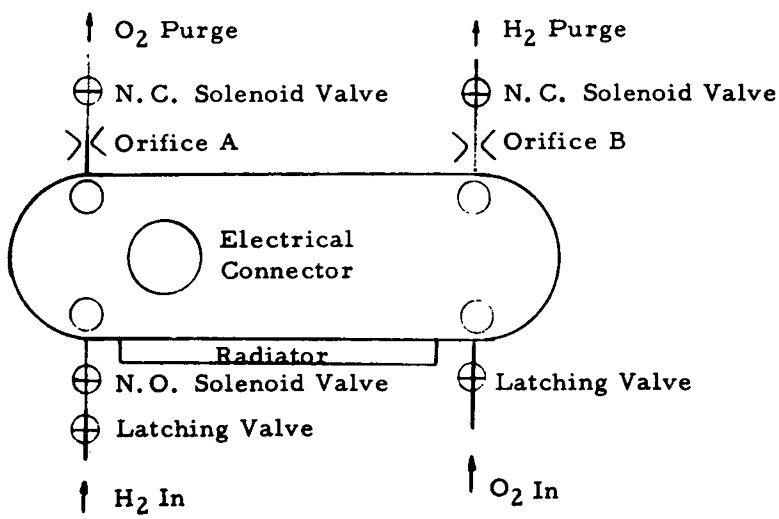
Proposed Purge Method for the HOPE Fuel Cell

I. Introduction

A purging system is required for the HOPE fuel cell module (1) to correct random voltage decreases on individual cells and (2) to correct a general voltage decrease in the total module voltage. The former condition, which has been termed a cell "nosedive", has been found to be best corrected by an H_2 vent purge. The latter condition is best corrected by an O_2 flush purge. The following paragraphs describe a pneumatic system and give pressure, flow, and time limits which should provide satisfactory purging for the fuel cell module.

II. Proposed Purge System

The proposed purge system uses the previous mentioned methods which can be accomplished as shown in the following schematic:

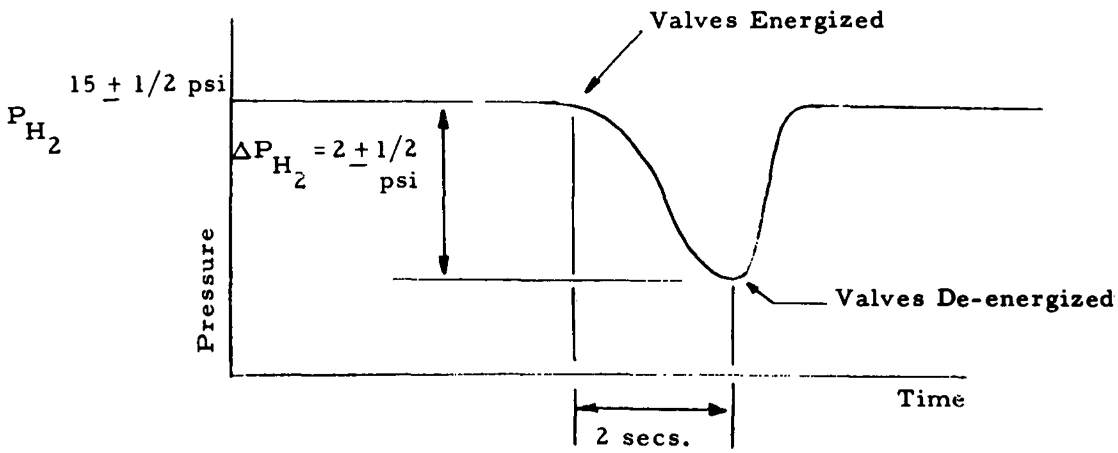


A. <u>Vent Purge Sequence</u> (Hydrogen Side)

1. H_2 fuel control valve (N.O. Solenoid Valve) and the H_2 purge valve (N.C. Solenoid Valve) are simultaneously energized.

2. When the H_2 pressure at the inlet to the fuel cell module drops to a value 2 ± 0.5 psi below the normal operating H_2 pressure, the H_2 fuel control valve and the H_2 purge valve are de-energized.

3. The H_2 pressure versus time is shown in the following curve:



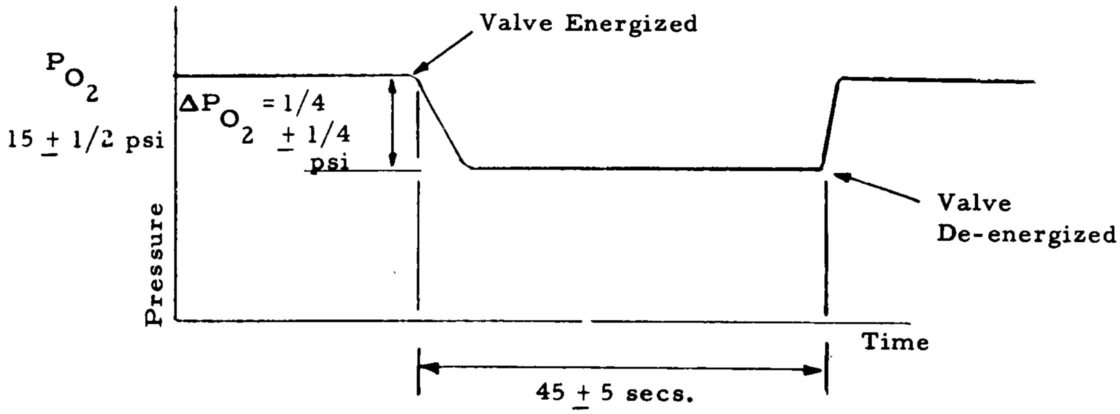
T and P_{H_2} to be determined by the most practical selection of purge orifice B. Consideration must also be given to the amount of H_2 being consumed at full load during the purge period.

B. Flush Purge Sequence (Oxygen Side)

1. O_2 purge valve (N. C. Solenoid Valve) is energized to open, causing the oxygen to flush through the module at the rate of 2000 ± 200 cc/min.

2. After a time interval of 48 ± 5 secs. the O_2 purge valve is de-energized and closed.

3. The O_2 pressure versus time at the module inlet is shown in the following curve:



III. Purge Sequence Initiation

A. H_2 Purge Initiation

The H_2 vent purge is to be initiated when the voltage on any group of 3 cells drops to 2.1 ± 0.05 volts or when the voltage on the remaining 2 cells drops to 1.4 ± 0.05 volts.

B. Repeat of an H_2 Vent Purge

The H_2 vent purge will be reinitiated after a period of 15 $\pm$ 2 secs. if the voltage on any group of 3 cells does not increase to 2.4 $\pm$ 0.05 volts or when the voltage on the remaining group of 3 cells does not increase 1.6 $\pm$ 0.05 volts.

C. Limiting the Number of H_2 Vent Purges

The number of H_2 vent purges is to be limited to 3 for each 2 hour period.

D. O_2 Flush Purge Initiation

The O_2 flush purge is to be initiated when the total module voltage drops to 27.5 $\pm$ 9.2 volts.

E. Repeat of an O_2 Flush Purge

The O_2 flush purge will be reinitiated after a period of 2 $\pm$ 0.5 minutes if the total module voltage does not increase to 28.5 $\pm$ 0.2 volts.

F. Limiting the Number pf O_2 Flush Purges

The number of O_2 flush purges is to be limited to 2 for each 2 hour period.

G. The H_2 and O_2 purge requirements are to be sensed, operated, and timed independently.

IV. Fuel Cell Operation on the Pad

Since the gas regulators are gauge type regulators, the gas pressure on the ground should be maintained at $P_p = P_{ATM} + 15 \pm 0.5$ psi. The purge system will have to accomplish the above purge cycles with the exception that P_o and P_h will be equal to P_p instead of 15 $\pm$ 1/2 psi.

APPENDIX 1-B

MANUFACTURING PROCEDURE - HOPE BIPOLAR COLLECTOR

APPENDIX 1-B

MANUFACTURING PROCEDURE - H. O. P. E. BIPOLAR COLLECTOR

DWG. # 1076520-188

STEP 1a.) Cut two pieces of .003 - .004" thick carpenter 20 CB to 5" x 10".

b.) Using the die # 1076520-188 in 1-74, have the ribs formed per Drawing 1076520-188. This die also punches two line-up holes in the pieces.

c.) Inspect every fifth piece for rib height.

STEP 2a.) Cut a .005" thick copper shim to 5" x 10". Use Cu B11B17A.

b.) Punch two holes from the same die as was used to punch the holes in Step 1.

STEP 3a.) Send out ribbed pieces, (2) to be copper plated and tin plated. Send copper shim to be tin plated. The plating is done by American Electroplate.

1.) Soak clean (diversey 808 or equivalent) and scrub with FFF pumice.

2.) Rinse.

3.) Dip in 1-1 HCl solution for ten seconds.

4.) Make anodic in Wood's Nickle bath for 10-15 seconds at 40 ASF.

5.) Make cathodic in Wood's Nickle bath for 4 minutes at 40 ASF.

6.) Plate for 3 minutes in Watts Nickle bath at 20 ASF.

7.) Rinse

8.) Make cathodic in a solution of KCN (6-8 oz. per gallon) for one minute at 40 ASF.

9.) Copper plate in Rochelle copper bath to .0004 - .0010" thick.

10.) Flame test plating adhesion.

3b.) Tin plate per usual methods:

3b. (Cont'd)
1) Vapor degrease
2) Rinse
3) Clean with Alkaline
4) Rinse
5) Tin plate (Alkaline or Acid) - .003" thick - Pure Tin.
6) Rinse
7) Dry and wrap

STEP 4) Trim the collectors and the shim leaving the two punched holes. A steel rule die is used for this operation with the two punched holes used to fix the location. This operation is carried out in 3-74 under M. Zuk. Die number 1076520-188.

STEP 5) All three pieces undergo a cleaning cycle.

A) Wash in a tank of Diversey 808 solution which is at 120°F for 3-5 minutes.

b) Scrub on a hard flat surface with pumice. A platers brush is used to prevent damaging the surface of the parts.

C) Spray with tap water.

D) Electrolytically clean for 1 1/2 minutes using a solution of Diversey 812 (180 grams of dry crystalline powder to every four liters of water). The solution is kept at 170°F and a six volt - ten AMP current is run through the solution while the piece is used as the cathode and is completely immersed in the solution. Each piece is done individually in this operation.

E) Spray with tap water.

F) Dip in a solution of fluoboric acid for 30 seconds. Use a nionel or a stainless hook for this operation as this acid attacks the regular pliers or forceps.

G) Spray with tap water.

H) Rinse in distilled water.

J) Dip in alcohol.

K) Hang up in cabinet to dry. The heat is provided with infrared lamps. Dry until all moisture on the faces has disappeared, then wrap as soon as possible.

STEP 6.) Assemble both collectors and the shim together with the ribs on the collectors facing outward and the shim in the center. Proper alignment is insured by the fixture provided in the hot press area which used the punched holes to line up the parts. The end of a twelve inch long copper tube is put between the collectors at one end. Mask all edges with tape. Scotch brand #X-1099, is put on first and this is covered with a layer of masking tape. Copper strips .025 - .030" thick are used to seal the end of the collector assembly with the copper tube. See Diagram #8 for further clarification. The copper strips are folded in the center lengthwise. Place these over the end of the collector assembly and pinch shut with pliers. The strip is then carefully hammered completely shut. To seal the end of the collector assembly cover these copper sealing strips with tape as were the other three sides of the collector assembly.

STEP 7.) Run the assembly in the hot press cycle.

A) Put the sealed assembly in the fixture with the .017" thick shims.

B) Attach the vacuum pump hose to the copper tube and evacuate the inside of the collector assembly to less than five inches of Mercury.

C) Heat the press up to 525°F, check this by a pyrometer.

D) Insert the fixture with the enclosed assembly into the hot press and increase the press to 300 pounds pressure.

E) Hold this condition for seven minutes, then turn the heat control dial on the press to 150°F and turn on the cooling water.

F) When the fixture itself is 200°F, check with a pyrometer, shut off the vacuum and open up the press.

G) Remove the collector from the fixture and remove the copper tube and end pieces.

H) Check every fifth piece for rib and flat heights.

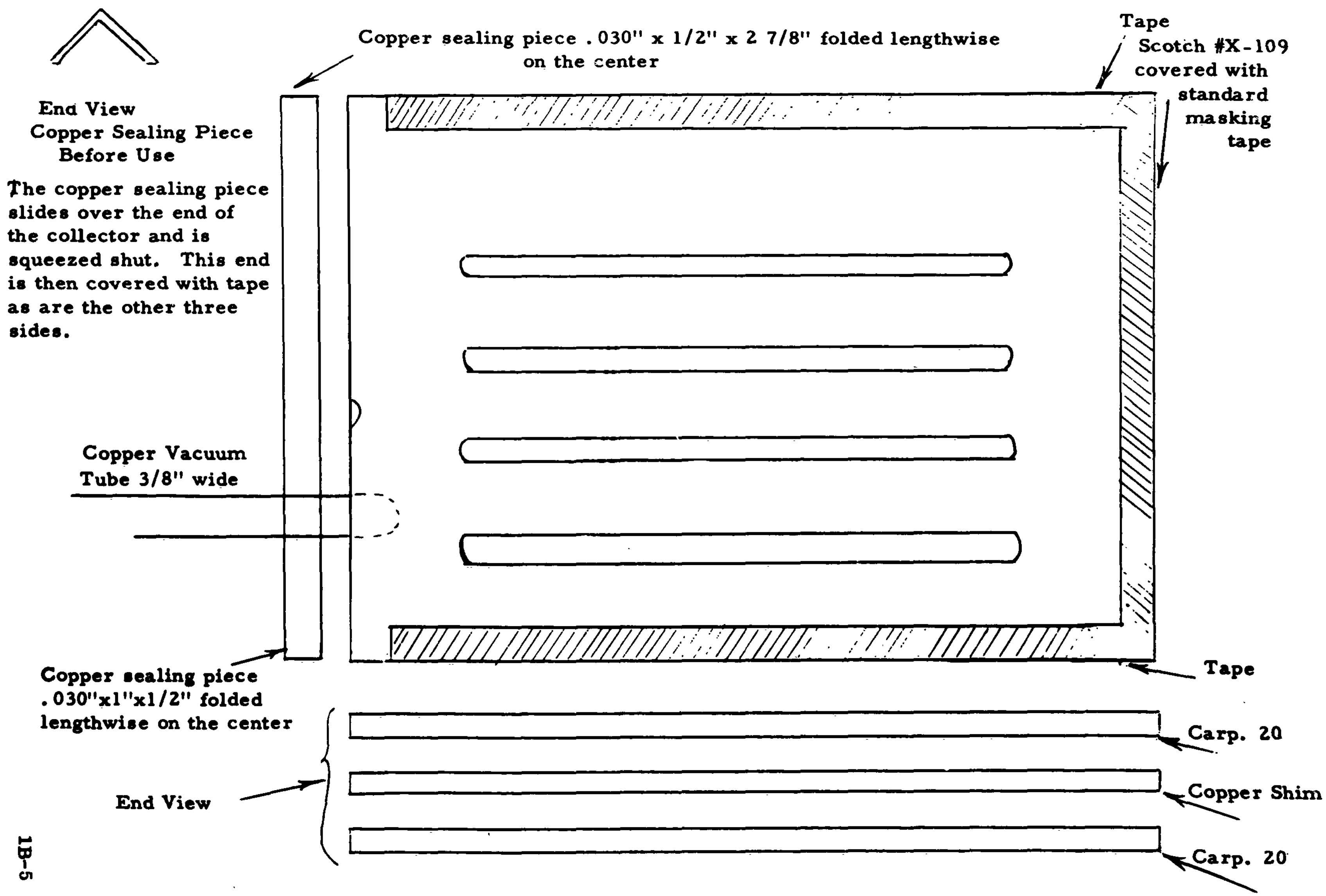
STEP 8) **Trim to the specifications of Dwg. 1076520-188 with the punch and trim die in 1-74 under Dempsey. Make sure that the hole from the copper tube is on the same end but directly opposite from the spot where the tab will be punched.**

STEP 9a) Use a "V" die to put the 90° bend along the length nearest to the voltage tab. This is a heat sink and must be perpendicular to the collector surface; therefore, no handwork can be done on these. Resolder the heat sink of the pieces separate. If any other portion of the collector except the tab is separated, the bond is not good and the piece is not used.

STEP 9b) The solder edge of heat sink must be sanded smooth with #1 sanding paper. Every 5th piece must be inspected for perpendicularity to face of ribs, must meet dwg. specs. Every 5th piece must also be checked for heat sink height (inside flat of collector to edge of heat sink). These checks should be on a batch basis and when deviations occur, batch should be back checked all pieces and remedial action taken, (conjunction with eng.) before proceeding job.

Preparation of the Collector for the Hot Press

Diagram #8



APPENDIX 1-C

ASSEMBLY INSTRUCTIONS FOR "HOPE" CELLS (2" X 6")

DWG. NO. 1076520-216

APPENDIX 1-C

ASSEMBLY INSTRUCTIONS FOR "HOPE" CELLS (2" x 6") DWG. NO. 1076520-216

Collector	Dwg. # D1076520-188	
Frame	Dwg. # D1076520-267	attached
Fuel Cell	Dwg. # D1076520-662	

1. All parts are now sent to the assembly room where every piece must be cleaned thoroughly. Every part receives a standard wash which is first, a solution of one (1) tablespoon of Alconox for every 1.5 gallons of hot tap water; second, a rinse in warm tap water, a rinse in cold tap water, and two rinses in distilled water. A liberal use of cleaning solvents, distilled water and boiling is necessary for all assembly operations because even the skin oil from one's fingers can prevent bonding or contaminate the membrane.

2. Preparation of the collector for bonding.

   a. Sand bond surface with #100 or #60 rough emery cloth. Continue process until this treated area has been thoroughly abrated and/or no smooth surfaces are visible. Rinse and sand the shiny parts that appear.

   b. Wash in Alconox, wipe with Toluene, and then use a standard wash. Item 1 above.

   c. Apply one coat of plastilok primer to the bond surface (this prepared by mixing 10 parts of Toluene, 55 parts of M.E.K., and 35 parts of #604 plastilok, all parts by volume). Air dry for 10 minutes and oven cure for 30 minutes at 180°F. Caution - do not get any of the bonding cement on the active part of the collector, i.e. the ribbed area.

   d. Apply one coat of plastilok cement, (#604 plastilok straight), air dry 10 minutes and pre-cure for 30 minutes at 180°F, then cure for 30 minutes at 325°F.

   e. Sand plastilok surface to remove gloss.

   Note: Do not proceed with "f" until steps of Section 3 are completed. Then do "f" of Section 2 and d of Section 3 together.

Assembly Instructions for HOPE Cells (2" x 6")

f. Apply one coat of thinned Bostick (2/3 Bostick #588-83 and 1/3 Toluene so that the viscosity is like that of hot syrup) to the bond surface and allow to dry in the air for 30 minutes. Apply immediately to the frame for bonding of the collector.

3. Preparation of frame for bonding.

a. Sand the bond area flat side (opposite to recessed-membrane side) with #60 grit cloth. Continue rinsing and sanding until no shiney spots are visible. File off any build-up of cycolac on end edges of tube slots and remove gloss of slot surfaces with the file.

b. Wash with Alconox and then use a standard wash.

c. Insert an 0.095" O. D. wire into the molded channels to prevent them from filling with cement. Leave sufficient wire exposed for removal after bonding is completed.

d. Apply one coat of thinned Bostick, exact mixture given above in step 2, to the bond surface on the flat side of the frame, allow to dry thirty (30) minutes in the air. The coat should be applied in a thin layer like water color with #2 brush.

4. Bonding of frame and collector. (See sketch #1).

Apply a coat of full strength Bostick to the bond surface on the frame. Immediately assemble the two together and clamp in the special fixture. This fixture consists of: a bottom epoxy glass laminate block approximately 8" x 3" x 3/4" with six bolts, two 1/16" thick rubber gaskets, two epoxy glass shims, 1/32" thick, 1/8" rubber gasket total outline type and on top another epoxy glass block. Wing nuts fasten onto the six bolts to apply pressure. Cure at room temperature for 20 hours. Heat sink is placed flush with dowels. Make sure cutouts on gaskets face same way as frame. Tighten wing nuts hard hand-tight with hand brace.

Assembly Instructions for HOPE Cells (2" x 6")

5. Installation of Nionel Tubes.

   a. Clean tubes of burrs and/or foreign matter with a 0.025" drill - wash with distilled water to insure removal of any fine residue.

   b. Remove the wire pins from the collector frame assembly.

   c. Apply Eccobond #55 - catalyst #9 to the 1076 520-267 P2 tubes, coat 1/2" of the tube length. Apply Eccobond 1/16" from inside end of tube to prevent plugging of tube.

   d. Insert the Nionel tubes into their frame grooves, leave the 1/4" non-cemented end of the tube outside of the frame, wipe away the excess Eccobond, clean the tube recess area. Leave 1/4" of tube protruding; make this measurement with ruler perpendicular to the tube recess in the diagonal area of the frame. Apply a slight fillet of Eccobond around the tube on the inside of the frame.

   e. Run a 1/32" fillet of Bostick around inside edge of frame to collector, all edges. Use syringe, but be sure to puncture all air bubbles in the cement. Do not cover Eccobond fillet around inner Nionel tube protrusion with the Bostick, just take it to the Eccobond, which should be pretty well started to set up before Bostick application. (Two coats of thin Bostick). Air cure for four (4) hours at room temperature.

   f. Run a 0.025" diameter drill through the tube to insure that it is clear.

   g. Check for freedom of flow through the tubes by submerging the collector frame assembly in distilled water and using helium at 10" H_2O pressure, bubble rate should be a fast boil affect in the Erlynmyer flask.

6. Preparation of frame and masks for bonding, (see sketch #2).

   a. Sand the fuel cell bond side of the frame (mask area-recessed side) with #60 grit cloth. Continue rinsing and sanding until no shiny spots are visible. Then wash with standard process, step #1 of these instructions. Now sand the mask (see sketch #2 for the area of the mask which is to be sanded) and the tape using #280 emery. Sand the tape on the roll, then apply to mask. Rinse, using distilled water. Tape over the depressions on the masks caused by the bumps. One layer of Permacel P252 tape is used.

   b. Apply a liberal coat of Bostick with a #2 brush to the bottom side only, and bake at 200°F for 15 minutes.

Assembly Instructions for HOPE Cells (2" x 6")

c. Apply Bostick, full strength, to the frame mask-area and mask; bond parts immediately and put in another arrangement of the fixture. The two epoxy glass blocks are the same as are the two 1/6" thick rubber gaskets. Only one shim is used and the 1/8" rubber gasket is shaped to the upper bond surface of the frame only. Air dry for 2 hours.

Note: The mask 90^{o} lip rests against the flat end of the collector and the flat end of the mask lays on the flat end of the frame. (See sketch #4).

7. Preparation of cell and frame for bonding.

a. Clean all the inside collector surface thoroughly. Use a scalpel with Toluene. Avoid getting Toluene on the frame - collector bond joint. Sand all bond areas of the frame including mask with #60 emery and give the frame a standard wash. Continue rinsing and sanding until no shiny spots are visible. Install assembly in filing fixture (heat sink side down, shim to prevent sideplay) file down cycolac edge of frame which is exposed at top surfaces of blocks. Use flat std. rasp file.

b. Prepare the bond area of the membrane on both sides (see sketch #4) by lifting the screen and gently sanding the colorless polymer membrane, after having pat dried this area with a Scott towel to insure desired effect of dry sanding. Use carbide for this. Either side of the membrane may face the frame.

c. The active area of the mambrane comes from the pilot plant, cut to fit, i.e. a 6" x 2" rectangle. The remaining portion of the membrane, wire mesh and polymer should be trimmed (if necessary) to fit into the recessed area of the frame. Do all trimming with scissors. Trim both screens 1/16" all the way around both sides to prevent short circuits. Caution - in cutting out the notches in the membrane to match those on the frame, do not allow the two screens to become intangled because if any contact occurs between the screens when the unit is running, a short circuit will occur. Pay particular attention to screen clearance around slot, should be 1/16". Do not cut polymer.

d. Keep electrode portion of the membrane wet. Put a piece of wet brown absorbent paper 2" x 6" on the outer surface of membrane, then cover with a Mylar sheet which is the same size as the cell active area on all sides. Pat dry cement areas (both sides) with Scott wiper.

APPENDIX 1-C

Assembly Instructions for HOPE Cells (2" x 6")

8. Cementing of Membrane (Cell) to frame collector assembly.

   a. Place a heavy coat, 1/32" thick, of Scotchcast Resin # XR5046 to the frame surface recess area, 1/8" back from width and length runs of the window, diagonally across the corners to the point of intersection and assemble the membrane.

   b. Bonding of top screen (Fuel Cell)

      1. Use early A. S. D. fixture dwg. # 1076520-215 (8) pcs.

      2. There are 6 plastic bags which contain the pressure pieces that make up this bonding fixture arrangement. These pieces are serialized (#1 thru #6).

      3. The cell assembly is installed in the fixture (Dwg. 1076520-215) collector side down. Item (6) below, is installed loosely to clear the bridge bolts in Item 4.

      4. The brown absorbent paper is put in place and the Teflon blank (catalyst area size) is placed on the catalyst area. Then the thick epoxy glass pressure plate is placed on top of the Teflon blank. Tighten the bridge bolts of the fixture (hand tight) which seals the active area from Scotchcast smear. Use a 5/8" or 3/4" washer under each bolt to prevent lateral movement of pressure plate.

      5. Apply (brush) on a medium layer of the Scotchcast cement # XR5064 to the exposed screen and surface beneath if screen is raised up.

      6. Install the (match-marked) cement area shaped Teflon pressure plates directly to the treated screens, pressing the screens down against the membrane.

      7. Install the wooden blocks on top of pressure plates (Item 6 above) and clamp into place with six (6) "C" clamps. Two (2) on each long side and one (1) on each end.

      8. Oven cure at 140°F for (5) hours.

      9. Leak and flow check cell assembly. After submerging assembly in water (without fixture) apply helium pressure of 15" H_2O and look for leaks. Then allow gas to flow thru cell for a second. Flow should cause a fast bubble rate. If either tube is restricted, clear with a 0.025 dia. drill.

Assembly Instructions for HOPE Cells (2" x 6")

9. Sanding Heat Sinks

Sand the flat of the heat sinks using #1 emery polishing paper. Lay the polishing paper on the marble slab, lean the cell against a right angle block to sand. Use blackening to find any high spots entirely perpendicular to the collector surface.

10. Cleanup of Cell Assemblies

a. Heat Sinks: Must be completely devoid of any cement.

b. Gas Tube Areas: All cement must be filed and sanded back to the original frame surfaces, regardless of surface. Tubes must be face up, cement.

c. Membrane to Frame Bonding: All Scotchcast cement residue must be cleaned (pared with scalpel and/or sanded) back smooth relative to any pileups and most emphatically, thoroughly removed from the tie rod slots.

d. Collector Ribs (External): (This directive particularly applies after bonding of the wicks to the collectors). All Bostick cement must be removed by application of Toluene (for light deposits) or scalpel removal for heavy deposits with Toluene to finish the job. KEEP TOLUENE AWAY FROM FRAME, AND FROM FRAME TO COLLECTOR BOND JOINT.

e. Install in filing fixture (heat sink down, voltage tab in), shim to prevent sideplay, file down cycolac edge even with the block surfaces to remove any excess scotchcast. Use a fine single cut file.

11. Installation of Permacel Tape # 252 on Collectors

Apply a piece 0.625" wide x 1.25" long to the cell assembly end (opposite voltage tap). Apply in such a manner that the length of the piece of tape runs the width of the cell assembly and the width of the tape overlaps, both sides of the assembly approximately 3/16".

Assembly Instructions for HOPE Cells (2" x 6")

12. Gas Flow Leak-Check of Cells

a. Use a water manometer check to assure freedom of flow through the cell. This is done by filling the cell with distilled water by means of a syphon tube, which just fits onto the gas tubes on the cell. Hook up the helium gas delivery tube through a water manometer and then to the gas tube at one end of the cell. A steady stream flow of water out of the tube at the other end of the cell must be obtained for a pressure setting of 12" of water on the manometer. Reverse the ends to check flow in both directions. Record results of this test by indicating passage or failure only.

b. Check for leaks by immersing the cell assembly (fixtured per sketch #3) in distilled water and using 3 psia. helium gas. The fixture has a bottom plexiglass plate with 5 studs, then the cell, a 1/16" rubber gasket, an epoxy glass shim, another 1/16" gasket, the top plexiglass plate and the wing nuts. If perimeter leaks occur through cement, reapply cement at the point of leak and re-process per steps "a and b", Item (8). The nature of the leak may require top screen lifting in the leak area only and membrane sanding before cement application.

13. Preparation of Wicks

a. Cut # 102-6th wicking material into strips 3/8" x 14". Boil wick material in a water and strip soap solution for 4 hours. Solution is made by mixing 170 grams of dry crystaline Diversey in a 4000 ml beaker of water.

b. Rinse several times in hot tap water.

c. Cool to room temperature.

d. Soak in "Solution A" for 15 minutes. Save solution and place back in the jug. Obtain Diversey and solutions in 1-46.

e. Rinse well in cool water.

f. Soak in "Solution B" for 15 minutes. Save the solution and place back in the jug.

g. Rinse several times in cool distilled water and allow to dry.

h. Cut wicking into strips 3/8" x 14".

Assembly Instructions for HOPE Cells (2" x 6")

14. Cementing of wicks to collector

    Wash off the collector side of the cell with Toluene and dry. Now without any other rinses, apply full strength, Bostick using the hypodermic needle. Apply two thin lines of thinned Bostick in each channel. These lines should be approximately 1/4 inch apart. Then place the three wicks so that the edges of the wicks are bonded to the collector. One end of each wick is flush with the voltage tab end of the collector. The other end of the wick protrudes at the other end. Place weights on and let dry in the air for 4 hours. Caution - clean off any Bostick which gets on the ribs with a scalpel because the Bostick will act as an insulator.

15. Testing bond strength of wick cement.

    Test wick bond strength by holding cell assembly in a horizontal attitude and having (1) pound weight on each wick. The pull should be perpendicular to the collector.

16. Drain all cells of water for storage purposes prior to pedigree test with brown wetting paper and Mylar installed thoroughly wet. Pat dry top of Mylar and other external surfaces of cell assembly. Do not cap inlet tubes.

17. Storage after pedigree test.

    Remove brown paper, wet membrane, apply clean Mylar to membrane (be sure Mylar fits membrane correctly) dry outer surface of Mylar and cell assembly, then place in dry polyethylene bag and seal with masking tape.

APPENDIX 1-C (Cont'd)

Assembly Instructions for HOPE Cells (2" x 6")

a1. Install the short leads on the voltage tabs with 0.050 dia. flat head brass rivets.

a2. Line up the lead with the tab in such a manner that the thickness of the terminal is in line with the thickness of the frame and the lead terminal is on the frame side of the voltage tab.

a3. Install the rivet with the head toward the collector side of the assembly.

a4. Back the head of the rivet with a suitable block and start the rivet set with a broad punch. Finish the rivet set with a flat punch. Be sure the lead terminals are in 180° alignment with the cell voltage tabs.

a5. Apply a light coat of Eccobond #55 with #9 catalyst to the lead terminal voltage tab rivet assembly and let cure with the rubber tube cement ("b, c, d," this section).

a6. Be sure to install brown wetting paper (thoroughly wet) under Mylar for this cure cycle.

a7. Resistance check-voltage lead to collector (lead end - adjacent collector area), use simpson meter - (1) ohm scale max. ohms = 0.002.

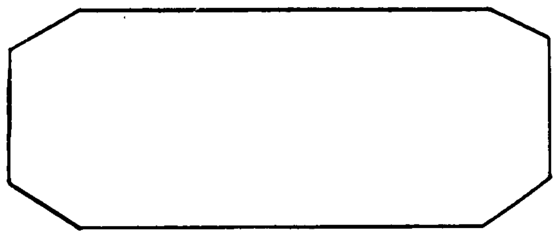
b. Clean Nionel tube recess area of frames with the special tool for this operation. This shall remove all excess cement around the tubes. Rotate the tool for best results. Be sure to clear the tool by tapping and blowing before using on the next assembly.

c. Cut two (2) pcs. of red silicone rubber tubing 1" long. Apply a ring of RTU Silastic 731 rubber around the Nionel tubes midway on the tubes.

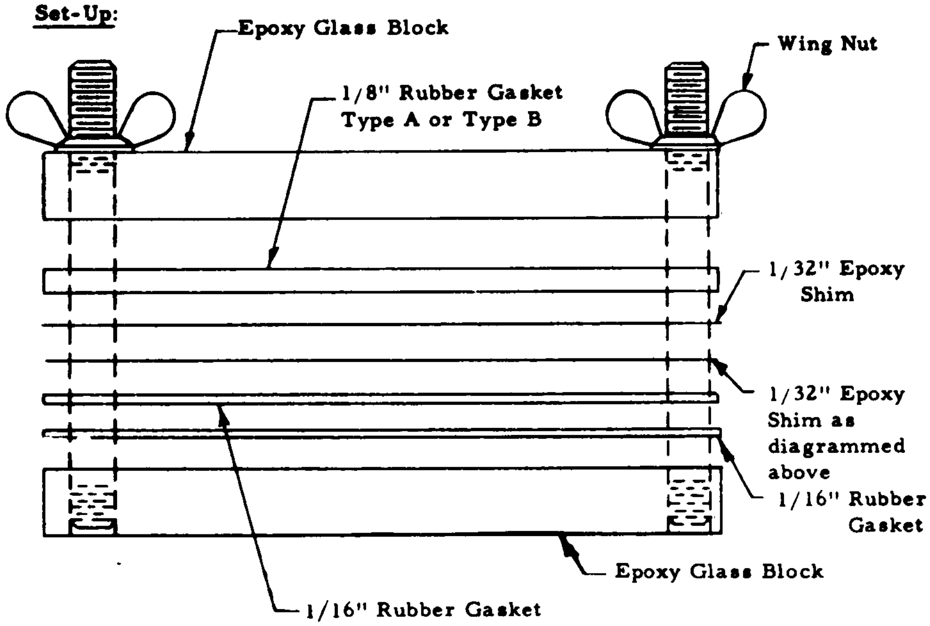
d. Install the rubber tubes flush to the bottom of the recess, fill in around tube and slot (all sides) with RTU and Spatula. Do not wholly fill the depressed side of the tube slot.

SKETCH NO. 1

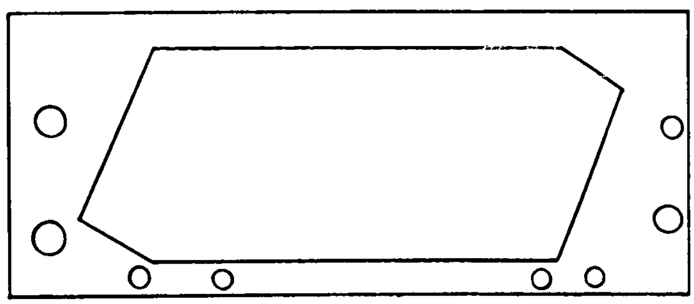
Shim



Set-Up:



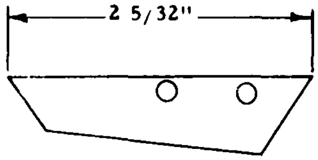
1/16" Rubber Gasket:



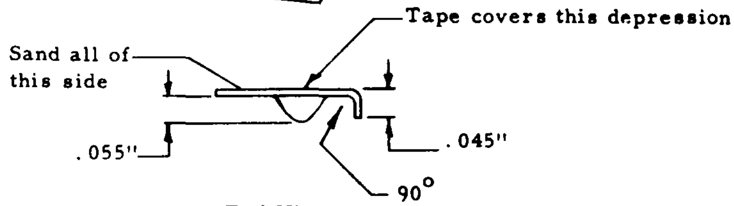
When setting up make sure cut outs on gaskets fact the same way as the cut out on the frame.

SKETCH NO. 2

Mask Preparation



When mask is in this position bumps are raised upward toward you. Sand lined area on this side and sand all other side.

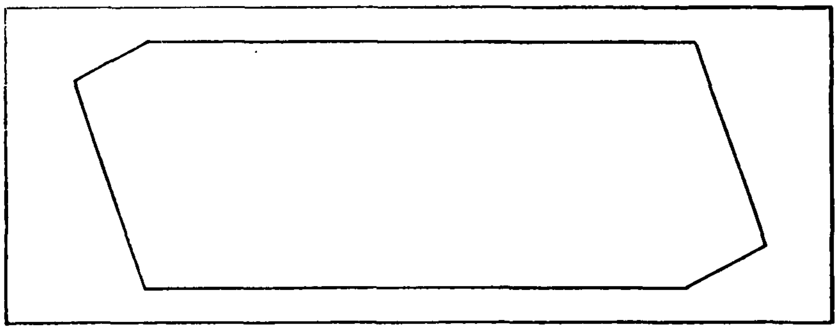


End View

Rubber Gasket on Fixture for Bonding

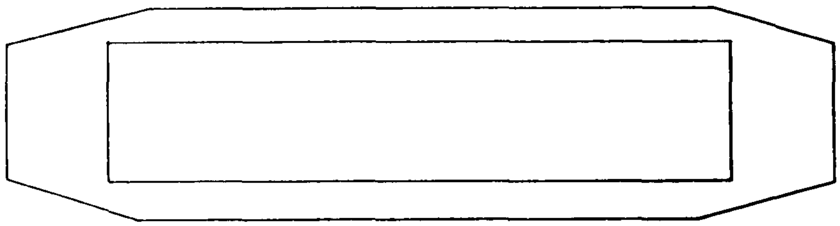
1/8" type for frame and collector

Gasket Type A



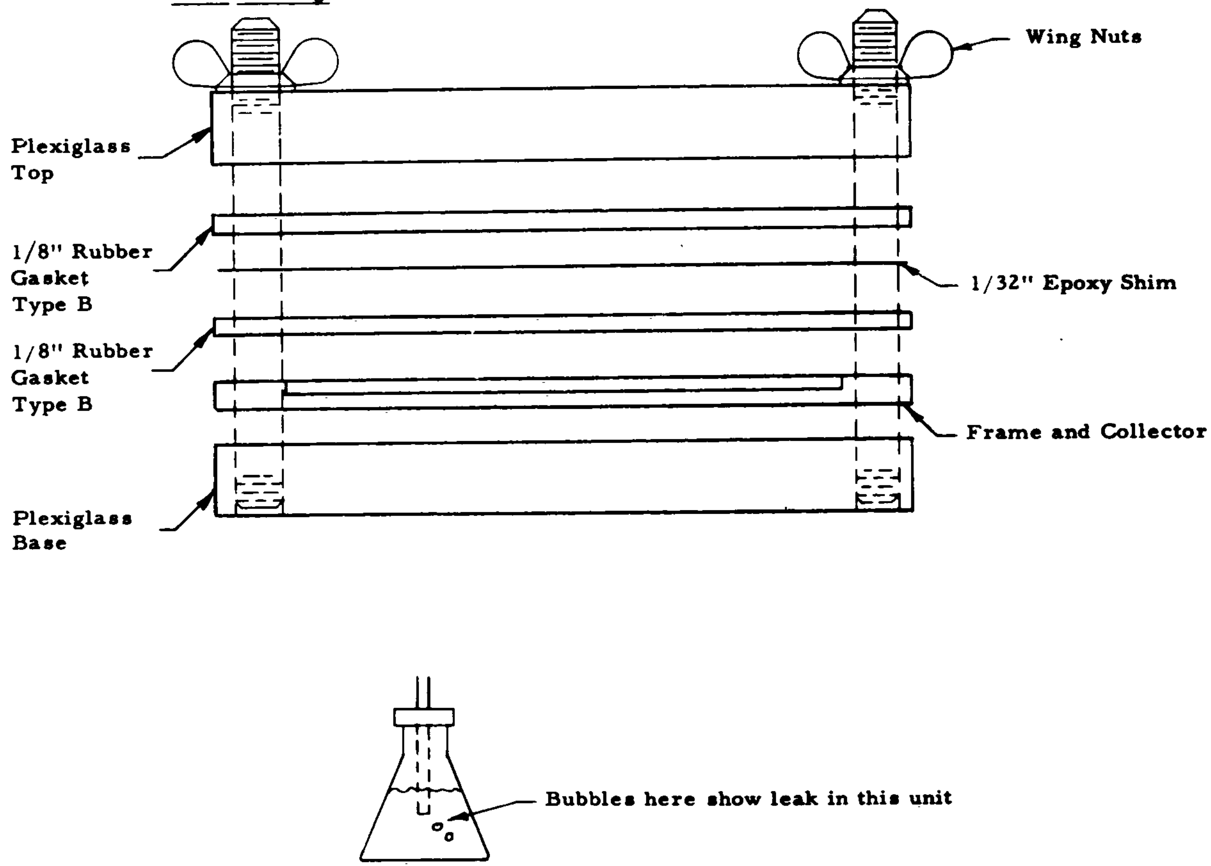
1/8" type for mask and membrane

Gasket Type B

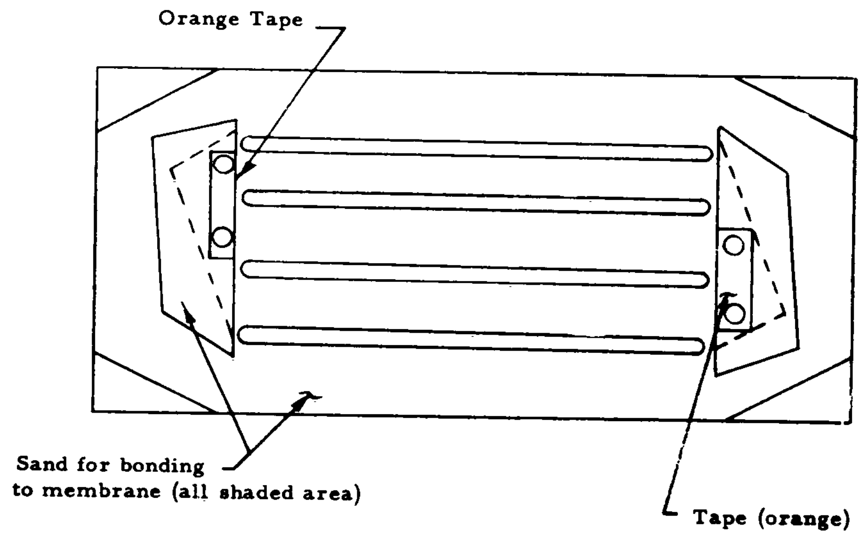


SKETCH NO. 3

Leak Testing:



SKETCH NO. 4



Orange Tape
Sand for bonding
to membrane (all shaded area)
Tape (orange)

APPENDIX 1-D

SPECIFICATION FOR "HOPE" FUEL CELL THERMISTOR

APPENDIX 1-D

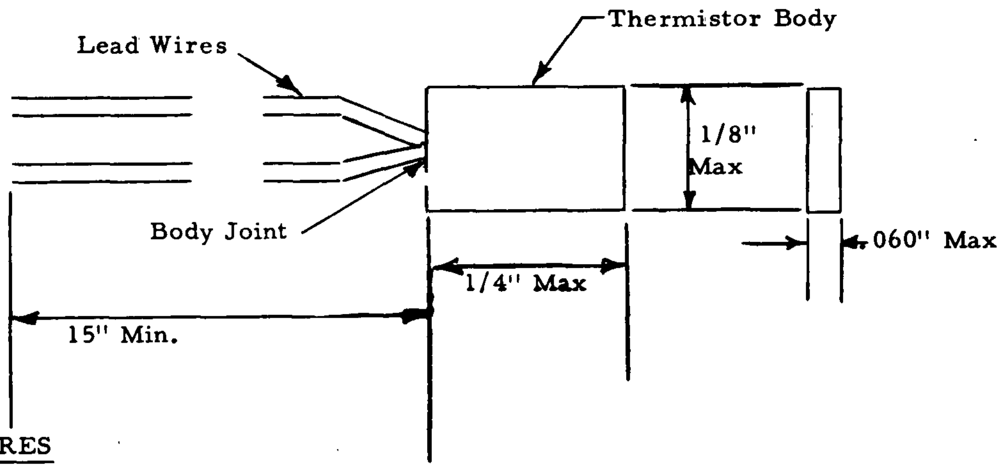
SPECIFICATION FOR "HOPE" FUEL CELL THERMISTOR

DESCRIPTION

This specification covers a thermistor temperature sensing device in which the resistance varies inversely with increased temperature.

CONFIGURATION

The thermistor shall have the following envelope maximum dimensions:



LEAD WIRES

The lead wires shall be Teflon insulated 30 guage stranded copper wire.

BODY JOINT

The body joint shall be sealed against moisture leakage into the thermistor body.

THERMISTOR BODY

The thermistor glass bead element shall be completely encapsulated in a waterproof epoxy body.

APPENDIX 1-D Cont'd)

SPECIFICATION FOR "HOPE" FUEL CELL THERMISTOR

ENVIRONMENTAL REQUIREMENTS

The thermistor shall be capable of operating continuously for 500 hours in the following environments:

Ambient - Oxygen at 100% relative humidity with possible submersion in water.

Temperature Range - 40°F to 200°F

INSULATION RESISTANCE

The thermistor shall exhibit an insulation resistance of 3 megohms between the water and each lead wire when submerged in water to a depth of 6 inches. The test voltage shall be 50 volts D. C.

RESISTANCE VS TEMPERATURE

The thermistor shall have the following resistance temperature characteristic. The tolerance on resistance shall be a maximum of plus or minus 15%.

TEMPERATURE (°F)	RESISTANCE (OHMS)
70	110,000
77	91,000
100	53,000
140	22,000
200	7,000

VENDOR IDENTIFICATION

Suggested vendor for this thermistor:

Gulton Industries
Metuchen, New Jersey

Vendor part number for this item is - L614

APPENDIX 1-D (Cont'd)

SPECIFICATION FOR "HOPE" FUEL CELL THERMISTOR

QUOTED PRICE

Vendor quote assuming no calibration.

QUANTITY	PRICE
10 thru 24	$7.90
25 thru 99	6.70

Quote assuming each is calibrated to following schedule is:

QUANTITY	PRICE
25 thru 99	$16.60

CALIBRATION POINTS

Each thermistor shall be calibrated by measuring its resistance at the following temperature points:

80°F
100°F
120°F
125°F
130°F
135°F
140°F
145°F
175°F
180°F
185°F

STATUS OR ORDER

An order was placed verbally for 25 thermistors to be calibrated and delivered on or before 9/26/62.

P.O. No. 201 A 20781145 M52NP

APPENDIX 1-E

PEDIGREE TEST PROCEDURE FOR HOPE CELL ASSEMBLIES

APPENDIX 1-E

PEDIGREE TEST PROCEDURE

FOR

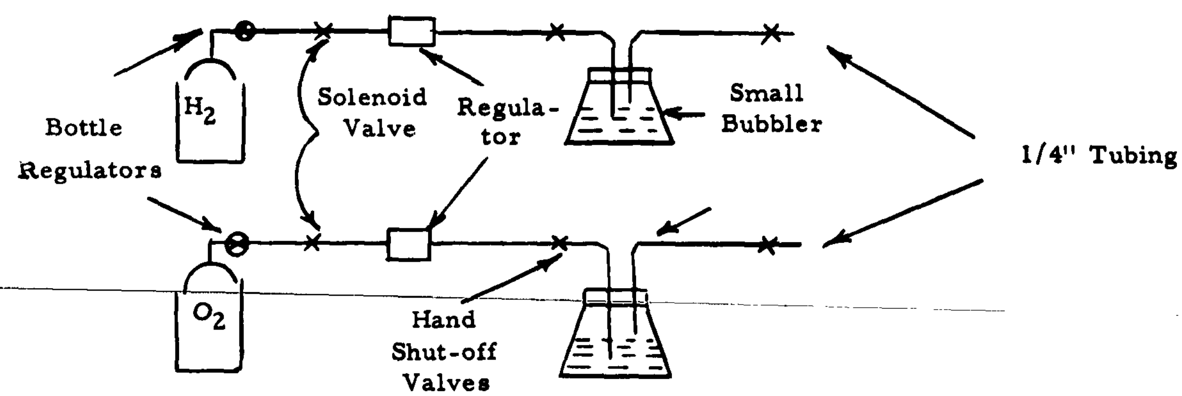
HOPE CELL ASSEMBLIES

A. Objective

To perform an operational performance test on fuel cell assemblies.

B. Equipment

1. Gas supplies with regulators, solenoids, bubblers, and shut off valves as shown below:



2. Variable load bank, Voltmeters and Ampmeters calibrated to within ± 1%.

3. Test fixture designed to hold a single cell assembly with a gasket to seal the O_2 side of the cell and with fittings provided for H_2 & O_2 inlet and purging.

4. Development test box (Lucite) designed to accommodate a stack of cells (up to 8 cells) with provision for individual cell H_2 feed and purge. Box also to be equipped with a circulating water heat sink.

PEDIGREE TEST PROCEDURE

FOR

HOPE CELL ASSEMBLIES

C. <u>Procedure - Single Cell Test</u>

1. Place single cell in test fixture. Be certain that gasket is in place and wing nuts tightened on the fixture to give minimum contact resistance.
2. Hang fixture in laboratory hood so that cell ribs run approximately vertical
3. Adjust gas line regulators to give 18 to 20 in. of water pressure to the H_2 gas and 8 to 10 in. of water pressure to the O_2 gas.
4. Attach H_2 and O_2 feed lines to the top of the cell and attach tied-off Tygon tubing to the bottom fittings for purging.
5. Purge the H_2 side by removing tubing, allowing gas to flow through for ~~3 or 4 seconds at a time. Repeat two or three times. Observe gas bubble~~ rate. Within 3 minutes the bubble rate should be less than 1 per minute. If cell exceeds this rate, return to assembly room for pressure check.
6. Purge the O_2 side in a similar manner. Bubble rate of O_2 may be as high as 30 per minute because of fixture sealing problems.
7. Attach power leads from fixture to load bank and attach voltage leads directly to the current collector plates.
8. Open circuit voltage should now be stable at one volt or above. If open circuit voltage is not stable, shut off gas immediately and remove cell from fixture. Return to assembly room for pressure check.

APPENDIX 1-E (Cont'd)

PEDIGREE TEST PROCEDURE

FOR

HOPE CELL ASSEMBLIES

9. Operate cells at loads of 1, 2.5 and 4 ampers in ascending order. Hold each point for approximately five (5) minutes. Voltage should be steady for approximately 2 of the 5 minutes. A short purge may be necessary before each reading to attain stabilized performance.

10. Record voltage versus current, time at each load, purges required, date and tester.

11. General handling precautions:

    a. Do not touch catalyst surface with hands or dirty surfaces.

    b. Keep catalyst surface covered with Mylar sheet at all times when not actually being tested. Add distilled water as necessary to keep a water film under the Mylar at all times.

    c. As soon as test or inspections are completed and Mylar cover applied, place cell assembly in dry plastic bag, fold over open end and seal with tape.

    d. Use extreme caution to prevent drying out of the cell from excessive purging, gas leaks in test fixture or lengthy exposure to ambient air.

Procedure - Stack Test

1. Assemble eight to ten single cells into a cell stack with appropriate end plates, current terminals and tie rods. (All cell assemblies must be complete with wicks.)

APPENDIX 1-E (Cont'd)

PEDIGREE TEST PROCEDURE

FOR

HOPE CELL ASSEMBLIES

2. Tighten the tie rods until the proper stack resistance is achieved. (Single cell assembly resistance x times number of cells plus end terminal resistance).

3. Attach single cell voltage taps and hydrogen feed and purge tubes. Instalı clamp holding stack into the heat sink.

4. Set heat sink water temperature control bath to $90^{\circ}F$ and curculate water through the test box.

5. Purge hydrogen through the cells one at a time. Observe hydrogen bubble rate 3 to 5 minutes to check for leaks. Bubble rate should not exceed 2 per minute.

6. Attach cover to the box and purge with oxygen. Again observe bubbler for oxygen leaks.

7. All cells should be reading over 1.0 volts at open circuit. If voltage at this point is less than 0.98 or unsteady, remove cell and return to assembly for pressure check.

8. Set 0.9 amp load on cell stack and run for 4 hours. Hydrogen pressure 18 to 20 in. H_2O and oxygen pressure 8 to 10 in. H_2O.

9. Record voltages of eacn cell every half hour and note any purging required.

10. At conclusion of test, return cells and data to the assembly room.

11. Observe same handling precautions as outlined in section C.

APPENDIX 1-F

INDEX

HOPE FUEL CELL MODULE ASSEMBLY PROCEDURE & RECORD

APPENDIX 1-F

INDEX

HOPE FUEL CELL

MODULE ASSEMBLY PROCEDURE & RECORD

Section A

Unit No.
Ass'y No.
Date

Section B

Special Instructions - Engineering

Section C

Cell Installation Sequence

Section D

Module Assembly **Procedure**:

1. Assembly of cells, spacer and end plates
2. Preparation of tie rods and nuts
3. Installation of tie rods and nuts and torqueing of the cell assembly
4. Installing of hydrogen (H_2) inlet and purge gas manifolds
5. Pressure checking of module assembly cells
6. Preparation of module cover assembly (top)
7. Installation of module cover assembly (top)
8. Connection of electrical wiring to cell voltage tabs
9. Ringout of circuitry connections made in item (8)
10. Pressure check of module cell assembly to cover assembly (top)
11. Installation of wick plate
12. Preparation of water collector (tank) assembly
13. Installation of water transport wick and pressure plate
14. Preparation of module casing
15. Installation of the module assembly (cell) and cover assembly (top) into the module container
16. Final pressure leak check of the module assembly

APPENDIX 1-F (Cont'd)

HOPE FUEL CELL

MODULE ASSEMBLY PROCEDURE & RECORD

DWG. #1076520 - 226 & 265

Section A

Unit No:__________________ Date:____________

Assembly No:_____________

Section B

Special Instructions - Engineering:

1 ____

2 ____

3 ____

4 ____

5 ____

6 ____

7 ____

8 ____

APPENDIX 1-F (Cont'd)

Section C

Cell Installation Sequence

Position No.	Cell No.	Comments

Section D

Module Assembly Procedure Dwg. # 1076520-226:

1. Assembly of cells, spacer and end plates

   a. Install thirty-five (35) cell assemblies, Dwg. # 1076520-216, in the module fixture, Dwg. #1076520-270, per sketch #1.

   b. Center the stack of cells between the end plates, Dwg. #1076520-267 P1 (top) and -207 P7 (bottom), heat sinks down and with the collector side of the cells toward the top end plate.

   c. Install the spacer, Dwg. #1076520-778.

   d. Install a "dummy" (collector - frame) assembly, as a terminal plate, on the oxygen (O_2) side of the number 35 position, "last" cell.

   e. Make sure that all the cell heat sinks are lined up straight by tapping cycolac edges of the cell frames (opposite side to heat sinks) lightly throughout this phase of the procedure so that they will all contact the casing wall equally flush. End plates and spacers should also be tapped flush.

      Note: The heat sinks of the cells are on the side opposite the hydrogen (H_2) gas "in" manifold.

   f. Maintain 6 7/8" overall length (outside of end plates.)

      Note: The stackup should maintain the above dimension. Engineering must be notified in the event that it doesn't.

2. Preparation of Tie Rods and Nuts

   a. Install the black shrinkable tubing on the tie rods, Dwg. # 1076520-211 P2, per dimensions shown in Sketch #1.

   b. Stake six (6) nuts, Dwg. # 1076520-211 P6 on six (6) of the tie rods (as marked for this assembly) by crimping the shank end of the nuts onto the tie rods. Be sure the tops of the nuts are flush with the ends of the rods before crimping.

3. Installation of Tie Rods and Nuts and Torqueing of the Cell Assembly

   a. Install the tie rods and nuts, Dwg. # 1076520-211 Ps & 6, tighten the loading end of the assembly fixture while tightening the tie rods. Prescribed spring load is 200 lbs. Tighten the fixture until the springs are 1 11/16" long. Use shims to fill the gap between the fixture and the module assembly. Tighten the tie rods snugly. Release the fixture clamp by turning (c.w.) the large nut in the center of the end face of the fixture. Remove stack from fixture then tighten each tie rod an additional 1/4 turn.

   Note 1: Maintain true alignment of all parts while tightening the tie rods.

   Note 2: The staked nut end of the tie rods is installed at the (top) end plate side of the assembly.

4. Installing of Hydrogen (H_2) Inlet and Purge Gas Manifolds.

   a. Cut seventy (70) cell connector tubes from the 0.040" I.D. by 0.110" O.D. silicone (red) rubber tubing each one inch in length for connection between the cell inlet and purge tubes and the H_2 inlet & purge manifolds.

b. Connect the tubes to the two (2) manifolds and cells (inlet & purge). Extreme care is needed to prevent puncturing or cutting the silicone rubber tubing.

5. Pressure checking of module assembly, Dwg. # 1076520-226, cells, manifolds and connector tubes.

a. 1 Install a piece of Tygon tubing on the main exit of the (H_2) gas manifold and clamp the Tygon tube tightly about (1") from the end.

a2 Reduce - adapt a piece of Tygon tubing to the (H_2) gas main inlet of the manifold and connect it to the Helium (He) regulated supply.

b. Set the helium (He) supply at 2.0 psi and observe the amount of helium (He) gas allowed to pass through the Erlenmeyer Flask. Rate should be high at first, but, if leaks are non-existant, the bubble rate should reduce to 0 in 2-3 minutes. If this occurs, submersion of the assembly is not required. If a leak is indicated by the bubble rate in the Erlenmeyer Flask after passage of (2-3) minutes, then submersion of the assembly in distilled water is required. When submersion is required, the following comprises the control record governing this procedure. Fill in pertinent information as prescribed here:

Test No.	Ass'y Initial	Pressure Used (He)	Cell Leak		Con. Tube Leak-Inlet M		Con. Tube Leak-Ex. M		Final Status
			Approx Loc.	Rem.	Approx Loc	Rem.	Approx Loc.	Rem.	
1									
2									
3									

Note 1: If no leaks are experienced, use work "none" in columns 4, 6, and 8 and enter "O. K. " or "REJ" in column (10) whichever applies on any and all tests required. If more than three (3) tests are required, add a sheet to this record.

Note 2: If submersion was not required, print across entire block of pertinent test number as follows: "No leak indicated - submersion not required."

6. Preparation of module cover assembly (top), Dwg. # 1076520-392 for assembly to the module assembly (cell), Dw. # 1076520-226. This assembly is found on module assembly, Dwg. # 1076520-265.

   a. Apply a very light coating of silicone grease to the main inlet - outlet ends of the hydrogen (H_2) gas manifolds. Make sure that none of the grease is allowed to enter the tube or pile up on the tube ends.

   b. Ring out (check) the wiring sequence, connector pins to each voltage tap to Dwg. # 1076520-214.

7. Installation of the module cover assembly (top) (Dwg. # 1076520-392) tc the module assembly (cell), Dwg. # 1076520-226.)

   a. Install the cover with the voltage top load wires at the same end as the voltage tabs of the cells.

   a. 1 Feed the gas manifolds of the cell module assembly easily into the seal retainer "O" ring assembly of the cover assembly (top). Make sure the tube entries are made simultaneously and squarely. Suggest two (2) pairs of hands for this operation. Continue pushing the cell assembly to the cover assembly until the top end plate of the cell assembly is against the rubber pads on the end cover.

a.2 Leak check non-submerged but submerge to determine location if leak is indicated. Note locations of leaks. Notify engineering of any leaks. If manifold or connecting tubes are at fault, remove and replace and/or repair (not action taken here and by whom authorized). If a cell or cells is at fault, disassemble, remove and replace and/or repair and replace (note action taken and by whom authorized).

a.3 Take the assembly to test and purge with H_2 gas and check open circuit voltage at heat sinks. Record voltages. If any cell voltage is below 1 volt, notify engineering before proceeding. Disassemble and replace and/or repair and replace faulty cells. (Note action taken and by whom authorized).

8. Connection of electrical wiring, Dwg. # 1076520-214, to the individual cell voltage tabs.

   a. Refer to wiring diagram, dwg. # 1076520-214, and connect cover leads to cell leads by soldering. Cover joint with silicone rubber tubing.

   Note; The wiring harness was bundled to afford leadout in close proximity to each cell. Take this into consideration to afford the most orderly fashion of connection.

9. Ringout of circuitry connections made in Item 9.

   a. Refer to wiring diagram, Dwg. 1076520-226 and 265, and check (ring-out) all cell voltage circuits from connector pins to cell heat sinks. Check for short circuit between each and all other cells - should be none. Make ringout check entries in chart provided on the next page.

APPENDIX 1-F (Cont'd)

CELL ELECTRICAL CHECKOUT

CELL POSITION	CELL NO.	CONTINUITY	SHORT CIRCUIT	COMMENTS
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				

10. Pressure check of module cell assembly to cover assembly (top).

a. Attach pressure line of helium (He) regulated supply to the external cover assembly top fittings (H_2 inlet and H_2 purge).

b. Apply 2.0 psi helium pressure and observe the helium bubble rate. The rate should be high at first; but, if leaks are non-existant, the bubble rate should reduce to 0 in 2-3 minutes. If this occurs, submersion of the assembly is not required. If a leak is indicated by the bubble rate after (2-3) minutes, submerge the assembly in distilled water. Fill in pertinent information as follows:

			Cell Leak		Con. Tube Leak-Inlet M		Con. Tube Leak-Ex M		
Post No.	Ass'y Initial	Pressure Used (He)	Approx Loc.	Rem.	Approx Loc.	Rem.	Approx Loc.	Rem.	Final Status
1									
2									
3									

Note 1: If no leaks are experienced, use word "none" in columns 4, 6, and 8 and enter "O. K." or "REJ" in column (10), whichever applies on any and all tests required. If more than three (3) tests are required, add a sheet to this record.

Note 2: If submersion was not required, print across entire block of pertinent test number as follows: "No leak indicated - submersion not required."

11. Installation of wick plate, Dwg. 1076520-399 P1.

    a. Lineup (reference) the proper slot for the first (#1 cell) wick entry into the wick plate and then feed all the wicks through their respective slots in the plate. Wicks from two (2) cells will go through each set of three (3) slots. Use the wick plate feeder tool (spring clip) to draw the wicks through the slots.

    b. Cut the wicks to a length of 1 inch extended beyond the wick plate.

12. Preparation of water collector tank assembly.

    a. Check the water collector tank, Dwg. # 1076520-299, for condition of its Solkafloc (BW-20) and replace if needed. Use 1.4 lbs. of Solkafloc. Use two (2) good handfuls at a time and pack firmly to insure that the container will take its full capacity.

    b. Check the water transport wick, Dwg. 1076520-186 for its condition and replace if required.

    b.1 Feed the transport wick (small end) through its boss on the cover assembly (top). Continue feeding the transport wick through the transport wick flexible tube.

    b.2 Tighten the nut on the module end of the flexible tube.

b. 3 Proceed with note below.

Note: Fill container to water transport wick inlet boss on the side of the tank. Feed in the transport wick and lay around perimeter, then continue filling with Solkafloc.

c. Install "O" ring, cover, and bolts.

13. Installation of water transport wick (module end), Dwg. 1076520-286 and pressure plate, Dwg. 1076520-399 P4.

a. Lay all cell wicks in even fashion in the direction of the "water transport wick" outlet and overlay these with the "pad" end of the "water transport wick."

b. Lay the "pressure plate," Dwg. # 1076520-399 P4, over the "pad" end of the "water transport wick." Make sure that the safety wire holes of the pressure plate line up with the mating holes in the wick plate. Safety wire the pressure plate to the wick plate. Tighten sufficiently to prevent any loose movement of the pressure plate.

14. Preparation of the module casing, Dwg. 1076520-212, for assembly to the module assembly (cell) which is now assembled to the cover assembly (top). This is detailed by Dwg. 1076520-265.

a. Line the cover with the (10") wide scotch tape. Four (4) pieces are used. The joints are at the rounded ends where it is overlapped (1/2"). Start the first two (2) pieces on each flat side. All sides must be perfectly smooth, free of wrinkles and air pockets.

a. 1 Start smoothing each piece by sticking it down at the starting end, raise the rest of the sheet, then push the remainder down to adhere, a small section at a time, by running fingers across the sheet while keeping tension on the unstuck portion.

b. Install the cover (bottom), Dwg. 1076520-395, to the casing.

c. Check the bolt holes of the casing for alignment with the bolt holes of the cover before installing the bottom cover into the container.

c. 1 Apply a thin coating of silicone grease, (Dow Corning) - high vacuum, to the perimeter bottom cover "O" ring and install it in place in its groove.

c. 2 Make sure that the scotch tape liner is adhering well to the entry surfaces of the container.

c. 3 Start the entry of the bottom cover as evenly as possible and carefully work the cover into place. Work the piece into the point of even engagement of the "O" ring to afford even entry of the "O" ring.

c. 4 Finish the entry evenly until the screw holes line up, then install screws; tighten screws snugly.

15. Installation of the module assembly, Dwg 1076520-226 and cover assembly (top) into the module container.

a. Check the bolt holes of the casing, sight align, to the bolt holes of the cover assembly (top) before installing the assembly into the container.

a. 1 Apply a thin coating of silicone grease, (Dow Corning - high vacuum) to the perimeter bottom cover "O" ring and install it in place in its groove.

a. 2 Make sure that the scotch tape liner is adhering well to the entry surfaces of the container.

a. 3 Start the entry of the top cover as evenly as possible and carefully work the cover into place. Work the piece into the point of even engagement of the "O" ring to afford even entry of the "O" ring.

a. 4 Finish the entry evenly until the screw holes line up, then install screws and tighten snugly.

16. Final pressure leak-check of the module assembly.

a. 1 Adapt - connect a short piece of Tygon tubing to a 1/4" A N tail-piece, connect the A N end to the hydrogen (H_2) exhaust fitting of the cover assembly and clamp the end of the Tygon tubing.

a. 2 Adapt - connect with a Tygon tube arrangement to another 1/4" A N tail-piece and connect the A N end to the hydrogen (H_2) inlet connector of the cover assembly.

a. 3 Cap off the A N oxygen (O_2) inlet.

a. 4 Leave the oxygen (O_2) purge fitting open.

b. 1 Pressurize the (H_2) inlet with 2. 0 PSIG of H_2 gas. Monitor the bubble rate. The bubble rate should be high at first; but, if leaks are non-existant, the rate should reduce to (4 bubbles per min. max.) after 2-3 minutes.

b. 2 If excessive bubble rate is indicated after above noted 2-3 minutes, check the following:

b. 3 Tighten all fittings on the cover, repeat (b-1).

b. 4 Thoroughly check the helium (He) supply system all the way to the assembly, repeat (b-1). If no leaks exist, record here (OK)____.

b. 5 Replace hydrogen (H_2) fitting "O" rings in the cover assembly, repeat (b-1).

b. 6 Disassemble the unit and repeat parts 6 and 12 of this section.

b. 7 If (b-6) above is required, note and record per instructions of parts 6 and 12 this section and add these additional records and this assembly record.

c. 1 Cap off the hydrogen (H_2) inlet and exhaust ports of the cover assembly (top).

c. 2 Cap off the oxygen (O_2) exhaust port of the cover assembly (top).

c. 3 Install the Tygon tail piece arrangement (used in "a-1" of this item) to the oxygen (O_2) inlet fitting of the cover assembly (top).

c. 4 Pressurize the oxygen (O_2) inlet with 1.0 PSI of helium (He) gas. Monitor the bubble rate. The bubble rate should be high at first; but, if leaks are non-existant, the rate should reduce to 0 after 2-3 minutes.

c. 5 If a bubble rate is indicated in (c-4) above, check the following:

c. 6 Tighten all fittings on the cover, repeat (c-4).

c. 7 Thoroughly check the helium (He) supply system all the way to the assembly, repeat (c-4).

c.8 Submerge the entire module assembly in distilled water, pressurize per (c-4) and monitor assembly for leaks. If leaks are detected, note and record area of leak here.

c.9 If leak indicated in (c-8) above is between container and cover, disassemble and replace container.

c.10 Repeat (c-4).

c.11 If leaks persist, contact engineering.

APPENDIX I-G

OPERATING AND MAINTENANCE INSTRUCTIONS

H. O. P. E. FUEL CELL SYSTEM

Model 7T-AE 15-A01

DIRECT ENERGY CONVERSION OPERATION

GENERAL ELECTRIC COMPANY

WEST LYNN, MASSACHUSETTS

October 1962

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SECTION I

INTRODUCTION

1-1 General

This publication includes operating and maintenance instructions for the HOPE Fuel Cell Power System Model 7T-AE15-A01 which is designed and manufactured by the Direct Energy Conversion Operation, General Electric Company, 950 Western Avenue, West Lynn, Massachusetts.

This power system will supply direct current electricity at the rate of 50 watts at 28 volts. The system consists of two fuel cell modules, each rated at 25 watts and 28 volts, and one dual compartment product water storage container. The water storage reservoir will store all the water produced by both the modules operating at rated load for 168 hours.

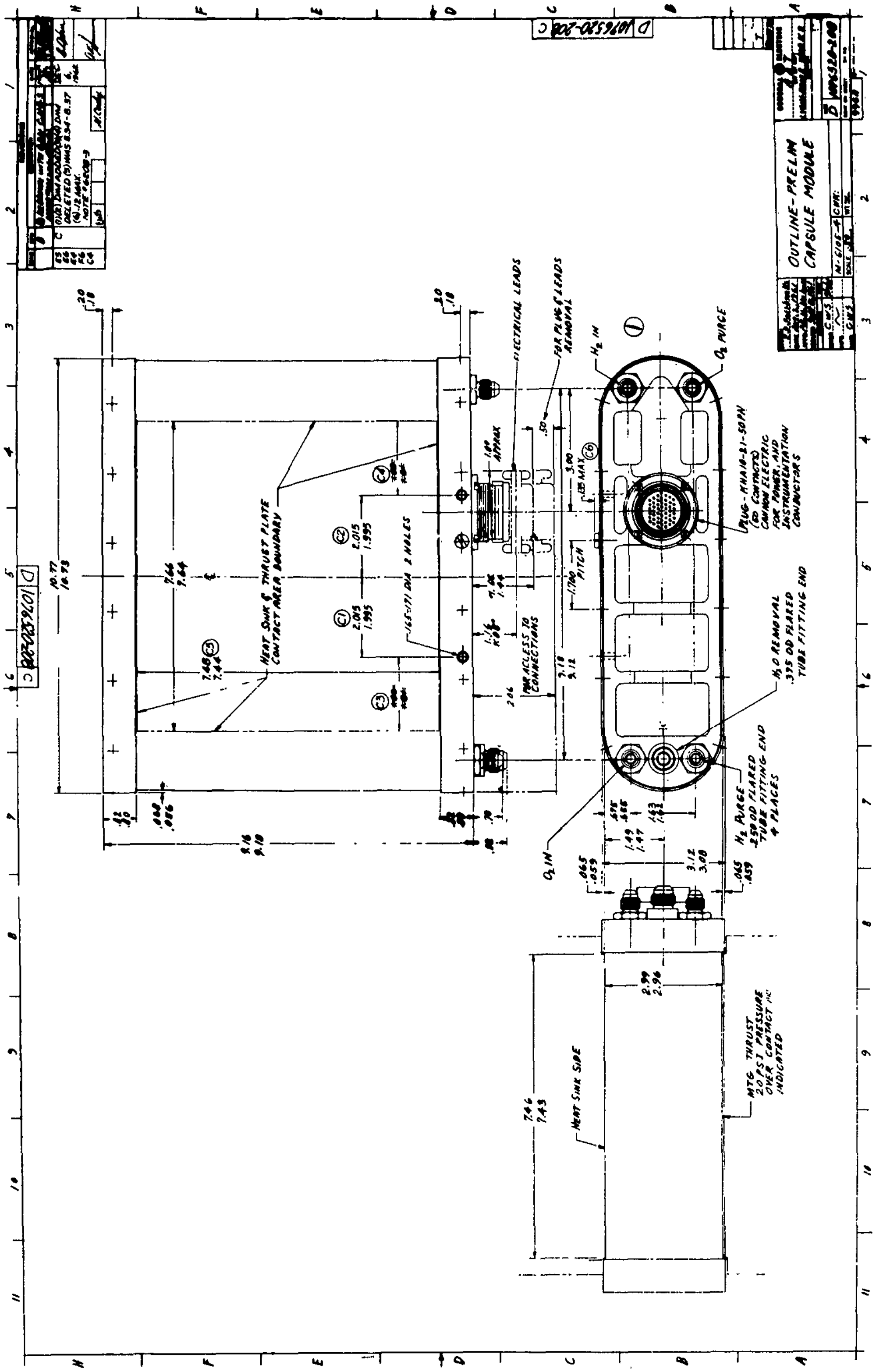
This power system is designed to operate in a zero gravity space vacuum at an ambient temperature of $90^{o}F$ to $110^{o}F$ while clamped to a heat sink which is maintained at a temperature of $90^{o}F$ to $110^{o}F$.

1-2 Specifications

The specifications for the HOPE Fuel Cell Power System are listed in Table I.

Table I - Specifications

Power Output	
Each Module	25 watts at 28 VDC
Each System (2 Modules)	50 watts at 28 VDC
Size	
Each Module (See Dwg. 1076520-208)	
Length	10.77 inches
Width	9.98 inches
Height	3.12 inches



OUTLINE-PRELIM
CAPSULE MODULE
ELECTRICAL LEADS
FOR PLUG & LEADS REMOVAL
HEAT SINK & THRUST PLATE CONTACT AREA BOUNDARY
HEAT SINK SIDE
MTG THRUST 20 PSI PRESSURE OVER CONTACT AREA INDICATED

Water Reservoir (See Dwg. 1076524-127)	
Length	17.69
Diameter (Flange)	5.78 inches

<u>Environmental Conditions</u>

Temperature - Heat Sink	
Operating	$90^\circ F$ to $110^\circ F$
Storage	$40^\circ F$ to $140^\circ F$
Temperature - Ambient	
Operating	Heat Sink Temp. plus $8^\circ F$
Storage	$40^\circ F$ to $140^\circ F$
Pressure	
Operating	0 to 15 PSIA
Storage	15 PSIA

<u>Fuel Supply</u> (for 50 watt system)

Pressure	
Hydrogen	15 ± 0.5 PSIA
Oxygen	15 ± 0.5 PSIA
Purity	
Hydrogen	99.97% Minimum
Oxygen	99.6% minimum
Flow	
Hydrogen	0 to 1 cu. ft. per hr.
Oxygen (without purge)	0 to 0.5 cu. ft. per hr.

<u>Life</u>

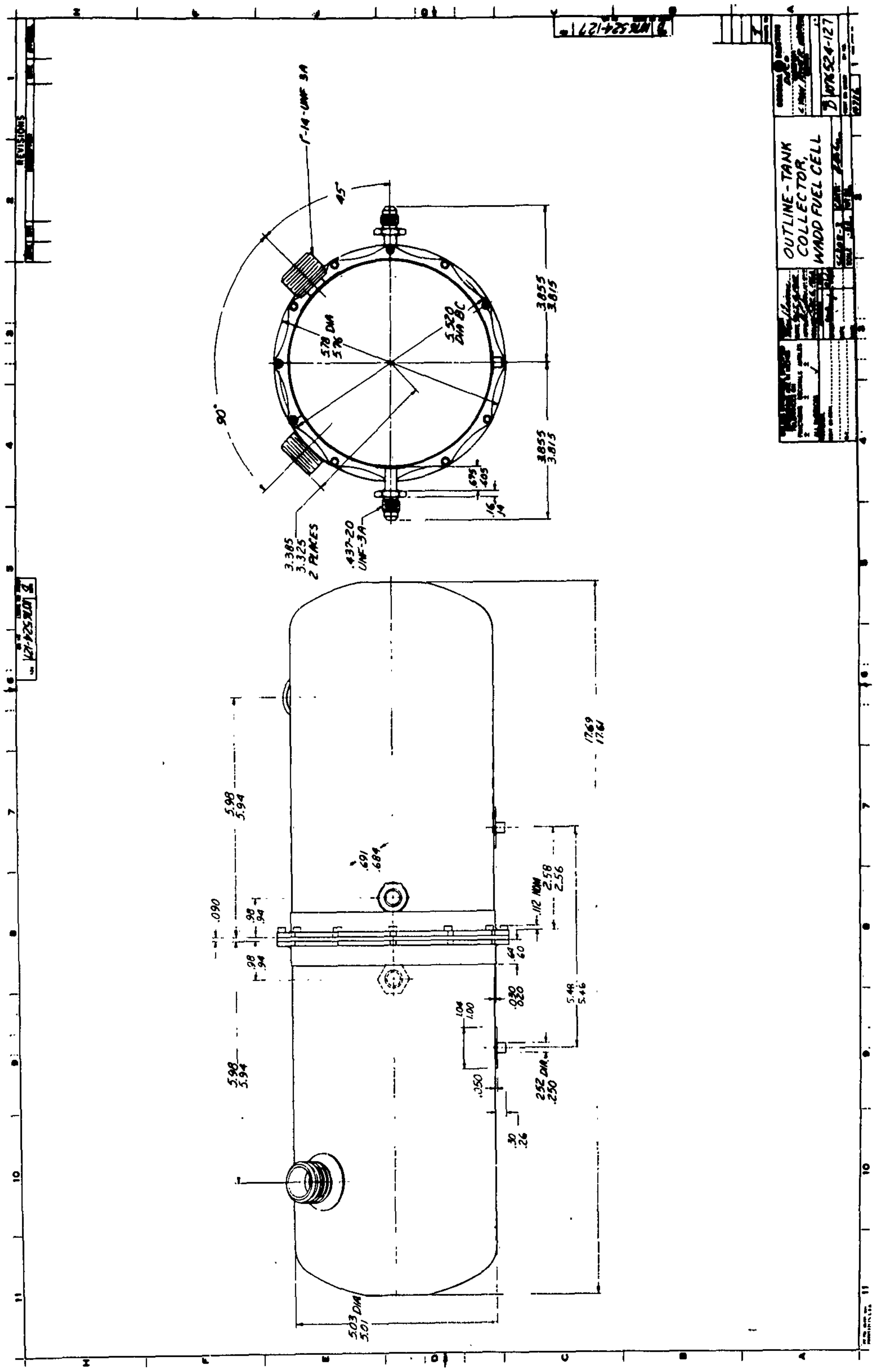
At Rated Power	340 Hrs.
In Storage	30 days

<u>Storage Methods</u>

0 to 2 day periods	H_2 & O_2 at 15 ± 0.5 PSIA
2 to 30 day periods	N_2 & O_2 at 15 ± 0.5 PSIA
Dead Storage or Shipping	N_2 flush then seal in polyethylene bag with wet pad (100 relative humidity)

<u>Water Storage Reservoir</u>

Wgt. of Solka Floc per compartment	1.4 lbs.
max. Wgt. of Water per compartment	4.5 lbs.


OUTLINE - TANK
COLLECTOR,
WADD FUEL CELL
XPA524-127
REVISIONS
1"-14-UNF-3A
45°
90°
5.78 DIA
5.76
5.520
DIA BC
3.855
3.815
3.855
3.815
.675
.605
.16
.14
3.385
3.325
2 PLACES
.437-20
UNF-3A
5.98
5.94
.691
.684
.090
.98
.94
.98
.94
.112 NOM
2.58
2.56
.64
.60
.030
.020
5.48
5.46
1.04
1.00
.350
.252 DIA
.250
.30
.26
17.69
17.61
5.03 DIA
5.01

SECTION II

OPERATING INSTRUCTIONS

2-1 General

This section describes the shipping method and the procedures used for initial checkout and the operating and purge procedures to be used during any lengthy testing period. Also included are steps to be taken for shut-down and methods of storage.

2-2 Method of Shipment from DECO

The HOPE Fuel Cell System consists of two fuel cell modules, one dual compartment water storage reservoir and two flexible transport wick tubes with disconnects.

Each fuel cell module is shipped with its respective flexible transport wick tube and disconnect. Special shipping caps cover the four gas connections. The caps are standard except for a drilled .020 hole. These prevent the fuel cells from incurring an internal reduced pressure due to consumption of traces of remaining H_2. Special shipping caps are also provided for the electrical connector and the water reservoir end of the transport wick tube. The transport wick tube is loosened at the fuel cell end and taped to the module end cover. The assembly is then placed in a heavy duty polyethylene bag with an orlon felt pad saturated with distilled water. The bag is heat sealed.

The dual compartment water storage reservoir is filled with absorbent (Solka Floc BW-20) prior to shipment. Shipping caps are provided for the transport wick connection and for the pressure equalizing O_2 gas connection on each compartment. The assembly is placed in a heavy duty polyethylene bag and heat sealed.

2-3 Unpacking and Storage Prior to Test

It is recommended that the fuel cell system be unpacked and tested as soon as possible after arrival at the Spacecraft Department. If the fuel cell cannot be tested immediately or connected to a gas supply, it is recommended that it be left in the sealed bags. The bags should be inspected for leaks and repaired if necessary.

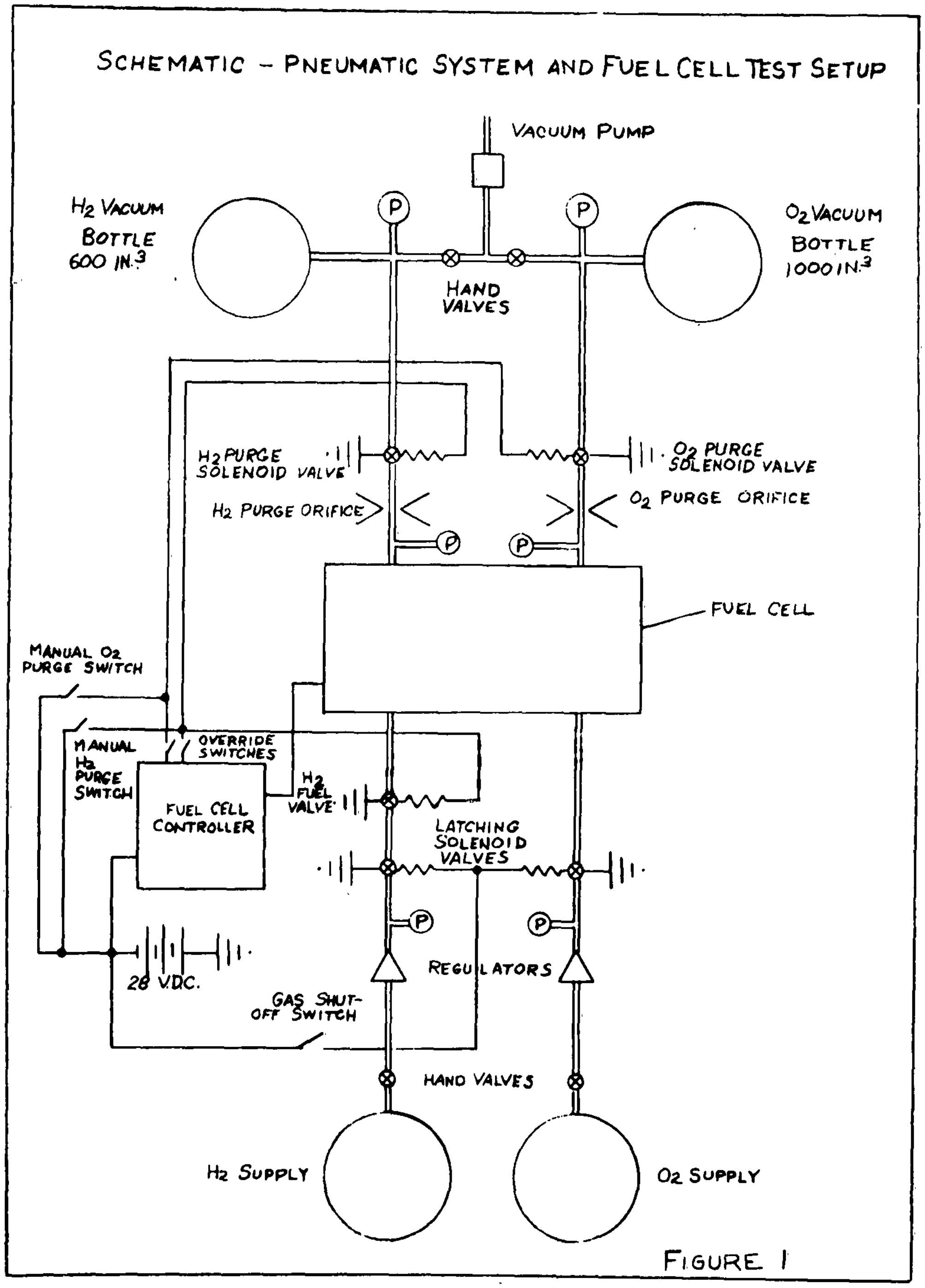
Storage life at shipping conditions has not been demonstrated and, therefore, a maximum time of five days from time shipped to time tested should not be exceeded.

2-4 Preparation for Operation

Before the fuel cell can be operated or tested, it is first necessary to provide a fuel supply and a temperature controlled heat sink and ambient. Table I gives the required fuel supply pressures and flows and the temperature at which the heat sink and ambient should be maintained.

For periods of operation up to one hour at full load, close thermal control is not necessary. These short tests can be run with heat sink and ambient at room temperature. It is assumed that the HOPE capsule space radiator will be used as the heat sink. The following procedure should be used to prepare the fuel cell for operation:

1. Mount the fuel cell module on the space radiator and clamp to required strap tension.
2. Connect hydrogen and oxygen lines from regulated gas supplies. Do not turn on gas. (See Figure 1 - Pneumatic System Schematic).


SCHEMATIC - PNEUMATIC SYSTEM AND FUEL CELL TEST SETUP
VACUUM PUMP
H2 VACUUM BOTTLE 600 IN.3
O2 VACUUM BOTTLE 1000 IN.3
HAND VALVES
H2 PURGE SOLENOID VALVE
O2 PURGE SOLENOID VALVE
H2 PURGE ORIFICE
O2 PURGE ORIFICE
FUEL CELL
MANUAL O2 PURGE SWITCH
MANUAL H2 PURGE SWITCH
OVERRIDE SWITCHES
FUEL CELL CONTROLLER
H2 FUEL VALVE
LATCHING SOLENOID VALVES
28 V.DC.
REGULATORS
GAS SHUT-OFF SWITCH
HAND VALVES
H2 SUPPLY
O2 SUPPLY
FIGURE 1

3. Plug in instrumentation 50 pin connector. (See Figure 2 for instrumentation schematic). Note the module open circuit voltage. It will probably be less than 5 volts.

4. Measure resistances of the nine module internal thermistors. (See Figure 3 for typical thermistor resistance - temperature characteristics).

5. Measure the thermistor insulation resistance by measuring the resistance between the three pairs of pins in the 50 pin connector according to the following table:

Measurement of Resistance Between:	Gives Minimum Insulation Resistance on Thermistors:
Pin No. 2 and Pin No. 38	J, F and C
Pin No. 6 and Pin No. 40	H, E and B
Pin No. 10 and Pin No. 42	G, D and A

insulation resistance should be at least 2 mehohms.

6. Connect transport wick disconnect at water storage reservoir and tighten fitting at module end. Position reservoir so that transport wick tube is horizontal.

7. Turn on hydrogen pressure to module.

8. Flush the hydrogen sides of the cells by opening the hydrogen purge line to atmosphere for three or four 1 second bursts of flow.

9. Check open circuit voltages on all cells. They should approach 1.0 volts.

POWER CONNECTIONS

PIN NO. 1 - (+) 28 VOLTS DC
PIN NO 36 - (-) COMMON

CELL VOLTAGES

PINS 1 THRU 36

THERMISTOR CONNECTIONS

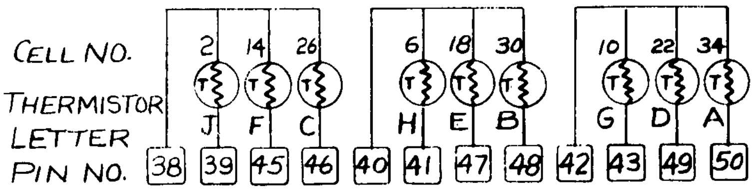


FIGURE 2 - INTERNAL INSTRUMENTATION
50-PIN CONNECTOR

Typical Thermistor Calibration
Qualification Unit Design
Gulton Industries Type L-614
Resistance Vs. Temperature
Negligible Self Heating
Thermistor No. 5

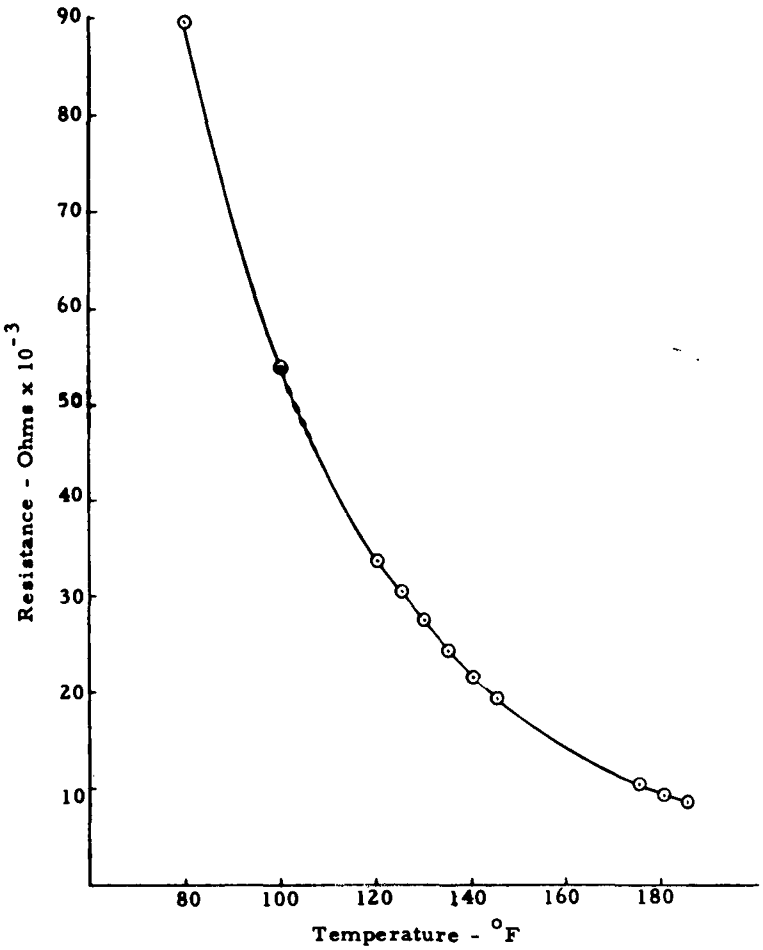


FIGURE 3

10. Turn on oxygen pressure to module and flush purge to atmosphere for 45 seconds. Then flush purge the water reservoir by flushing the O_2 through the reservoir.

11. Recheck open circuit voltages on all cells. All cell voltages should be above 1.0 volts.

12. Apply load. Load resistance at rated power is approximately 32 ohms. Set load current at 0.9 amps.

13. Measure module voltage and individual cell voltages. Module voltage should be above 28 volts and all cells should be above 0.8 volts.

14. Remove load and note open circuit voltages on all cells. They should again approach 1.0 + volts.

15. Unit is ready for operation.

Generally the above procedure will result in satisfactory load carrying capability of the fuel cell for short periods of time. For longer periods (15 minutes or more) it is recommended that the purge pneumatic system be used for purging. Such a system provides more uniform removal of inerts from the hydrogen sides of the cells. A discussion of the purge procedure is in Section 2-5.

2-5 Operation and Purging

As soon as all individual cell voltages at open circuit (no load) have stabilized at 1.0 to 1.08 volts and the module demonstrates capability of holding rated load of 0.9 amps, the system is ready for continuous operation. During continuous operation each module requires periodic purging of the H_2 and O_2 sides for removal of inerts. The purge pneumatic system is shown schematically in Figure 1. The system can be divided into three major parts: the vacuum system, the gas supply, and the controls.

The vacuum system consists of vacuum bottles for the H_2 and O_2 sides and a vacuum pump to maintain vacuum pressure at 0 to 5 inches of mercury.

The gas supply system provides H_2 and O_2 at 15 $\pm$ 0.5 PSIA.

A hydrogen vent purge is accomplished by simultaneously opening the H_2 purge solenoid valve and closing the H_2 fuel valve. Then, reversing the process when the pressure within the H_2 side drops four inches of mercury. The H_2 purge orifice must be sized to accomplish the pressure decay in about 2 to 3 seconds.

An oxygen flush purge is accomplished by opening the O_2 purge solenoid valve for 15 seconds. The O_2 purge orifice must be sized to provide an O_2 flow rate of 1700 to 1900 cc/min at a maximum pressure drop in the O_2 side of the fuel cell of 0.5 PSI. During the O_2 flush purge, the O_2 inlet valve remains open.

During normal operation of the fuel cell, the purge valves remain closed and the H_2 fuel valve and latching solenoid valves remain open. The gas pressure thus is dead ended in the fuel cell and the gas flow is equal to the rate of gas consumption by the cells.

The purge cycle consists of one H_2 vent purge followed by one O_2 flush purge. Tests have shown that stable operation of the fuel cell will result when it is purged as follows:

a. One purge cycle every 2 hours, plus

b. One purge cycle whenever any individual cell voltage drops below 0.6 volts (or when any group of 3 cells drops to 2.25 volts or when the group of the last two cells in each module drops to 1.4 volts.

The control portion of the system consists of the fuel cell controller and the manual switching system. The controller senses voltages of eleven groups of 3 cells and one group of 2 cells (35 cells in each module) and initiates a purge cycle when the voltage on any group drops to the minimums discussed above.

If it is desired that the modules be purged manually, the override switches are opened to cut out the controller.

During normal operation of the fuel cells, the heat sink should be maintained at $100 \pm 10^{\circ}F$ and the ambient surrounding temperature should be controlled at 8 to $10^{\circ}F$ above the heat sink temperature.

The fuel cell is designed to operate continuously for 168 hours and has a life of at least 340 hours.

2.6 Shutdown Instructions

Shutdown of the fuel cell is accomplished by merely reducing the load or current to zero. The rate at which the load is applied or reduced is immaterial. The flow of gas into the cells will decrease to almost zero as soon as the load is removed; however, a slight flow will continue until the catalyst on the cells adsorbs its capacity. After this happens the flow becomes extremely small due only to diffusion of hydrogen through the solid electrolyte.

At open circuit the cell voltages will rise to between 1.05 and 1.08 volts.

The gas pressures on the cell will be maintained by the regulators at 15 ± 0.5 PSIA. The regulators must be capable of maintaining the pressures within the specified limits even when the flow has decreased to zero.

Each compartment of the water storage reservoir can absorb up to 4.5 pounds of water. This represents the amount of water produced by one fuel cell when operating at 25 watts for 206 hours.

When the water storage reservoir becomes filled to capacity, the absorbent has to be removed and replaced. To do this, the tank is disassembled by removing the flange screws. Dry Solka Floc BW-20 is then packed into the tank.

2.7 Storage

The recommended methods for storing the fuel cell at open circuit (no load) can be summarized as follows:

Short Period	-	0 to 2 days
Long Period	-	2 to 30 days
Dead Storage	-	over 30 days

Short Period Storage - Short period storage is defined as operation at open circuit (no load) during checkout of system or during week-end shutdowns. During non-operating periods like this, the fuel cell may be left with the H_2 and O_2 gas turned on and controlled at correct operating pressure.

Long Period Storage - Long period storage is defined as storage at no load for indefinite periods of time up to 30 days in length. This may be required, perhaps, when major changes are being made in test equipment. During these periods, the hydrogen should be removed from the fuel cell modules by flushing with nitrogen. The flushing procedure is as follows:

a. Disconnect hydrogen supply to fuel cell.

b. Connect in its place a nitrogen supply regulated at 15 $\pm$ 0.5 PSIA.

c. Crack H_2 purge line upstream of the H_2 purge orifice and pulse the flush flow 3 times at 2 seconds each.

d. Retighten the purge line.

The fuel cell module is thus pressurized with nitrogen and oxygen for the duration of the storage period.

Dead Storage - A dead storage period is defined as shipping time or storage for indefinite time. Preparation for shipping has been discussed in a preceding section. Preparation for dead storage is assumed to be identical to preparation for shipping.

Satisfactory operation of the fuel cell after long periods of dead storage has not been evaluated.

SECTION III

MAINTENANCE

3-1 General

This section describes the techniques that should be used in trouble shooting a malfunctioning fuel cell module and the associated repair procedure. It is assumed that any repair which requires disassembly of the module will be performed under the supervision of DECO trained personnel. Sufficient detailed instruction cannot be included in this document to enable disassembly of the module by the customer.

3-2 Trouble Shooting and Repair

The trouble shooting and repair of a malfunctioning fuel cell module can be somewhat simplified if the procedures in Table II are followed. Table II contains the malfunctions most likely to occur based on previous experience with the fuel cell. Each malfunction is accompanied by a number of possible causes and simple tests that should be performed in attempting to isolate the cause. The repair procedure is also included.

TABLE II - MALFUNCTIONS

Malfunction	Possible Cause	Tests	Repair Procedure
1. Excessive hydrogen consumption - no load - all cell voltages above 1.0 volt	a. Internal Module Leak b. External Module Leak	a. Pressurize H_2 side with 2 PSIG Helium and note leakage flow from O_2 side. b. Pressurize H_2 side with 2 PSIG Helium and note leakage when module is submerged in water	a. Disassemble module for closer examination b. Replace O-rings on fittings
2. Excessive hydrogen consumption accompanied by one or more cell voltages below 0.8 volts at open circuit.	a. Cell Leak b. Shorted cell (electrode to electrode or cellector to collector)	a. Pressurize H_2 side with 2 PSIG Helium and note leakage flow from O_2 side b. Pressurize H_2 side with 2 PSIG Helium and note no leakage flow from O_2 side	a. Disassemble module and replace cell b. Same as 2a
3. Excessive oxygen consumption - no load - all cell voltages above 1.0 volt	a. Internal Module Leak b. External Module	a. Same as 1a b. Pressurize O_2 side with 2 PSIG Helium (with heat sink and pressure pad surfaces of module rigidly supported) and note leakage when module is submerged in water	a. Same aa 1a b. Replace O-rings or whatever part is leaking.
4. Low voltage all cell - rated load.	a. Inerts Accumulation b. H_2 Starvation c. O_2 Starvation d. Flooding with Product Water	a. Purge H_2 & O_2 sides - corrects. b. Check H_2 supply to module c. Check O_2 supply to module d. Crack O_2 inlet or purge line fitting (whichever is lowest) and note water flow from O_2 side. Check amount of water in reservoir by weighing reservoir.	a. None b. None c. None d. Remove water from module Examine wick disconnect, replace absorbent in reservoir.

TABLE II - MALFUNCTIONS - Cont'd)

Malfunction	Possible Cause	Tests	Repair Procedure
5. Low voltage on one or two cells at rated load	a. Inert Accumulation	a. Purge and note voltage increase	a. None
	b. Cell Leak	b. Purge and note only momentary voltage recovery then try 1a	b. Replace cell.
	c. Poor connector contact	c. Remove load and note little or no voltage change. Purge and note no voltage change. Try 1a note no flow, remove 50 pin connector and check voltage at pins.	c. Clean connector pins.
	d. Broken internal wire	d. Same as 5c. Measure voltage from next lower cell to next upper cell and note a voltage of 2 volts.	d. Disassemble and repair wire.
6. Incorrect Temperature reading by thermistor.	a. Bad Thermistor	a. Measure resistance - note it is too high by more than 15% (see Fig. 5)	a. Disassemble module and replace thermistor.
	b. Broken internal lead	b. Measure resistance - find it is infinite.	b. Disassemble module and repair lead.
	c. Bad thermistor insulation (shorted to collector)	c. Measure insulation resistance as discussed in Section 2-4	c. Disassemble module and test thermistors individually and replace defective one.

APPENDIX 1-H

TEST INSTRUCTIONS

APPENDIX 1-H

TEST INSTRUCTIONS

Subject: Acceptance Test for H. O. P. E. Fuel Cell Modules Q1 thru Q5

Date: October 10, 1962

Equipment:

(1) H. O. P. E. fuel cell module

(2) Water storage reservoir for testing purposes

(3) MSD fuel cell controller

(4) H. O. P. E. module test setup with pneumatic purge system

Procedure:

(1) Set environmental chamber at 108°F and heat sink at 100°F

(2) Set H_2 pressure at 15 inches H_2O and O_2 pressure at 12 inches H_2O.

(3) Set 0.9 amps load, without fuel cell controller connected, and operate unit until voltage on all cells is stable. Purge when required to obtain maximum operating performance.

(4) Connect fuel cell controller and test for correct operation.

(5) Operate unit for a continuous period of 48 hours using the following purging procedure:

a. 2.2 second H_2 vent purge plus a 15 second O_2 flush purge whenever a cell nosedives. (Controller should sense this condition and automatically H_2 purge stack.)

b. 2.2 second H_2 vent purge plus a 15 second O_2 flush purge every 2 hours in addition to above.

c. Purge as in (a) and (b) whenever power output drops to 25 watts. Do not allow power to drop below 25 watts.

APPENDIX 1-H

TEST INSTRUCTIONS

Procedure:

(6) Unit must not be shut down (barring emergency) without approval of engineering.

(7) Data to be recorded every hour.

(8) Data to include following:

(a) Total volts

(b) Amps

(c) Power

(d) Individual cell voltage

(e) H_2 and O_2 pressure

(f) Heat sink temperature

(g) Chamber temperature

(h) 9 cell temperature thermistors (resistance)

(i) Time of purging

APPENDIX 1-J

PROJECT HOPE

FUEL CELL

ZERO GRAVITY DISCUSSION

PRESENTED TO USAF ASD

August 21, 1962

AREAS OF DISCUSSION

I. Analytical review of various fuel cell functional phenomena from the standpoint of possible effects during zero gravity operation.

II. Analysis of data acquisition system from the orbital flight for determination of performance effects from zero gravity operation plus other types of failure analysis.

III. Discussion of other possible worthwhile zero gravity experiments in support of the HOPE Project and other Fuel Cell Projects.

I. Analytical Review of Gravitational Effects on IEM Fuel Cells - Stability under Zero-G

This report summarizes the analysis of Ion Exchange Membrane Fuel Cell behavior under essentially Zero-G, as presented to the USAF ASD in Dayton, Ohio, on August 21, 1962.

Introduction:

Although IEM Fuel Cells are designed for orbital and space applications, rather little experimental evidence regarding stability under nearly zero-G is presently available. However, such evidence may not be required if basic knowledge regarding liquid and gas phase behavior under such conditions is well known and understood. The purpose of this report was to undertake a phenomenological analysis of fuel cell components, in order to understand the possible effect in the absence of gravitational forces on these components. Such an analysis may then lead to the application of well-known concepts to some systems components and to the requirement of a refined analysis and possibly experimentation regarding less well-known concepts and influential parameters.

Information Sources:

This analysis is based on:

1. Experience and information acquired at the DECO-Fuel Cell Laboratory while working on IEM Fuel Cells.

2. Literature references as presented in Appendix I.

3. Discussion with scientists from the General Engineering Laboratory, Schenectady, New York.

Analysis

Macroscopic and Microscopic Component Analysis:

This phenomenological study is based on a model presented in Appendix I. The figure represents one electrode-electrolyte interface, electrode section, gas phase and current collector. Cell components have to be considered on microscopic (porous electrode, possible current collector roughness, etc...) and macroscopie (flat plate behavior of electrode and collectors) scales.

Macroscopic component behavior can be assumed to be understood and based on experimental evidence (i.e. mixing of liquid and gases depending on hydrophilic or hydrophobic characteristics). However, it should be noted that Reynolds's theory on minimized potential energy rather than minimized surface energy, seemed to raise doubt as to the behavior of liquid-gas interfaces under equilibrium conditions. (Reynolds's theory leads to the existence of dispersed phases under zero-G as compared to the existence of defined interfaces observed experimentally. Reynolds pretended that non-dispersed phases could only be observed under non-equilibrium conditions. However, it seems that Popov, during his 25-hour flight, demonstrated the stability of a non-dispersed interface.)

Characteristic Dimensionless Groups

Dimensionless quantities defined as Bond (B_o for gravitational and capillary forces), Weber (W_e for dynamic forces) or Reynolds group (Re_e for eddy/shear forces) will determine relative gravitational influences. Table I represents approximate values for these groups as applied to cell components.

TABLE I

Dimensionless Groups for IEM Fuel Cell

	Macroscopic Scale	Microscopic Scale
B_o	0.13	10^{-14}
W_e	10^{-6}	10^{-6}
Re_e	0.5	--

Group values close to unity indicate behavior similar in presence or absence of gravitational forces. This would be the case for the behavior of a liquid on a large flat plate as defined by R_o and for existence of laminar layer thickness as defined by Re_e. However, should the surface become flooded and display ripple-formation, low W_e-values would predict surface geometry capillary-controlled at gas flow rates of about 1 cm/sec.

What should be concluded, presently, is the capillary-controlled water-droplet formation due to $B_o \sim 10^{-14}$.

Hydrostatic and Quasi-Hydrostatic Conditions

Quasi-hydrostatic conditions define phenomena occurring at rather low rates.

1. Liquid-Gas Capillary (quasi-stationary)

   This process will be capillary-controlled as defined by B_o 10^{-14}. However, Figure 2, Appendix II, shows the displacement of the interface for large Bond number variations. Thus, the only possibilities would be surface drowning (if the contact angle > 0, which is the case) or capillary liquid disappearance, should the contact angle be < 0.

2. Surface Retention of Water-Droplets

   Capillary-controlled - no influence - if the surface becomes drowned, water would flow to current collector (macroscopic behavior).

3. Time-Dependent Droplet Geometry

   Unaffected in microscopic regime. In macroscopic regime behavior predictable from experiments on liquid-gas mixtures.

4. Droplet Formation on Collectors

   Can be treated macroscopically - Result identical to liquid-gas system under zero-G.

5. Electrode Wicking

   Capillary controlled. Essentially unaffected by zero-G.

Hydrodynamic Conditions

1. Gas Flow Over Flat Plates

   Flow is laminar and unaffected by zero-G as shown by Re_e. Stability of laminar flow occurs for $W_e < 3$ or $Re < 200$.

2. Diffusional Process - Gas-Gas and Gas-Liquid Diffusion

   Unaffected - Diffusional process not appreciably G-dependent.

3. Convective Flow

None present under Fuel Cell operation conditions, but for heat flux which is not dependent on gravitational affects.

Time-Dependent Transients and Non-Transients

1. Vibrational Effects - These effects could be analyzed for a simple capillary model. However, simple experimentations would yield faster results. Processes would probably not be too vibration-dependent, whereas component may display short-life.

2. Shock - Single or multi-pulse high "G" shock could according to previous analysis cause pore-flooding and result subsequently in variation in electrode properties. Again this will depend on the amplitude of liquid-level changes, according to Figure 2, Appendix II. Component deterioration should also be investigated.

Note: Results of analysis presented above yield:

1. Liquid film stability in electrode under zero-G.
2. If heat transfer poorly evaluated, surface flooding will respond to macroscopic effects.
3. Magnitudes of meniscus level variations have to be investigated, preferably experimentally.
4. Mass (H_2O) transport process remains unchanged, inclusive of wicking conditions.
5. Interfacial water transport conditions unaffected.
6. Vibrational and shock effects should be investigated.

Influence of Zero-G on Process Rates

Since most of the processes occur in similar fashion in presence or absence of gravitational effects, it remains to be shown how rates might be affected.

1. Kinetic electrochemical processes are unaffected.

2. Absorption - Desorption are not rate-limiting.

3. Electron transfer properties are unaffected.

4. Diffusional rates unchanged, but maybe for geometry (configuration) change in the meniscus in electrode capillaries.

5. Evaporation and condensation are unchanged. No nucleate boiling expected to occur.

6. Convective flow would be G-dependent. However, no mass transport by convection occurring.

7. Radiation may affect rates of heat rejection. (This can be incorporated into engineering designs).

Suggested Experimental Work

In lieu of conclusion, it is suggested to conduct experimental work:

1. On the complete system, i.e. design simulating final design. (Note that Bond numbers can remain unchanged if the new configuration is properly calculated. This would allow experimentation under various G-levels.)

2. On specific studies, i.e. investigation of liquid meniscus behavior under zero-G, high G-values and short-duration shock.

3. Develop an analytical model to interpolate results to various environmental conditions.

II. Failure Analysis:

A preliminary failure analysis has been made in order to see how the currently planned system of orbital data acquisition may be used to distinguish between different failures and performance effects related to zero gravity operation. A considerable amount of additional effort is required for a more complete program of failure analysis and induced failure testing. This work is proposed for a later phase of the program. The characteristics chosen for study at this time are as follows:

1. Accumulation of inert gases.
2. Internal hydrogen gas leaks
3. Loss of radiator cooling
4. Flooded hydrogen electrode
5. Flooded oxygen electrode
6. Increase of contact resistance
7. Transport wick failure

Since the ion-exchange membrane fuel cell contains a solid electrolyte and there are no moving parts in the H. O. P. E. system, the only area for concern at zero gravity conditions is the movement of the product water. Failure of the product water to move properly will be reflected in a voltage degradation of the cells as the active area of the cell becomes flooded thus masking some of the reaction sites. Since the other characteristics listed also are reflected in cell voltage degradations, it is necessary to show how each may be distinguishable.

1. Accumulation of Inert Gas:

Signal: A relatively slow and steady drop in voltage of all cells.

Action: The automatic purge controller will sense the low cell voltage and initiate the principal H_2 and O_2 purge.

Analysis: Immediate performance recovery will be observed from the first purge. Also, from the known amounts of inert gas present in the supplies, the rate of decay or purge frequency required to sweep out the inerts can be calculated and compared.

2. Internal Hydrogen Gas Leak:

Signal: A fast voltage drop of one or more adjacent cells. Pressure of hydrogen and oxygen in the module will become equal. Temperatures of cells in the area of the leak will rise fast.

Action: The automatic purge controller will initiate the purge sequence at the prescribed voltage. However, the performance will not recover from the purge and will continue to drop until another lower voltage sensing point is reached on the automatic controller, at which time it will shut off the gas supplies to that module and disconnect it from the electrical load. An additional sensing will be through the thermistors which will trigger the same shut down sequence if 180°F is exceeded.

Analysis: A review of the telemetered data for voltage drop purging effects, pressure changes and cell temperatures will define the condition of a leaking cell.

3. Loss of Radiator Cooling:

Signal: A gradual rise of temperature on all cells with time without a corresponding rise of radiator temperature.

Action: Eventually the overtemperature sensor through the thermistors will shut off the gas supplies and remove electrical load from the unit.

Analysis: The gradual increase in ΔT between the cells and the radiator will define this condition.

4. Flooded Hydrogen Electrode:

Signal: Fairly fast voltage decay of one cell or a couple of randomly positioned cells.

Action: The automatic purge controller will sense the low voltage of a cell and initiate the prescribed hydrogen and oxygen purge.

Analysis: The rate of performance recovery following a purge will be slower then in the case of the inerts and may require two or three purge sequences to recover full performance. The frequency and rate of recovery are distinguishable from the inerts. The effect on the fuel cell water management system due to zero gravity operation can, therefore, be determined by correlating the purge frequencies and cell performance with that experienced during ground testing.

5. Flooded Oxygen Electrode:

The characteristics and analyses of this type of problem are essentially the same as for the flooded hydrogen electrode, except that the effect on cell performance will probably be observed on a greater number of cells at a time, and the degradation of performance will be at a much slower rate. Also, from the telemetered data, this behavior can be correlated with ground test experience.

6. Increase of Contact Resistance:

Signal: A low voltage output of all cells.

Action: The automatic purge device will initiate the prescribed purge cycles.

Analysis: In the case of increased contact resistance, it will probably occur suddenly and effect all cells. This is most likely to occur during the launch phase. The purging will not produce any significant recovery and the automatic device will continue to call for a purge as frequencty as the timer will allow.

7. Transport Wick Failure:

Signal: A steadily decreasing voltage from a steadily increasing number of cells. Effects should be noticed in the low numbered cells first.

Action: Automatic purging device will sense the low voltages and initiate the purge sequences as prescribed.

Analysis: With no product water being removed from the module, the oxygen side of the cells will gradually flood, with the cells nearest the exit being effected first. The repeated purging will have some short time improvement but will become less and less effective with time. It is considered desirable to incorporate some type of water flow sensor in the transport wick line or sensors in the storage tank to determine the amount of water stored. In the early phase of the program a survey was made to find such sensors but none were found adequate. Another survey of the field should be made to see if any new developments are now available.

III. Other Experiments:

Consideration was given to other zero gravity experiments which might be run in support of the H. O. P. E. project and to provide additional data and understanding of the water transport behavior under zero gravity conditions. The following test vehicles were considered:

1. KC-135
2. RVX
3. Mercury
4. HOPE Capsule
5. Drop Towers

The following experiments suggested are for purposes of discussion and consideration only and are not meant to imply that they are required for the success of the HOPE project:

1. Observe water droplet behavior on actual Polymer A membrane surface in KC-135 flights at zero gravity.

2. Observe transport wick behavior and Solka Floc storage material at zero "G" in a Mercury flight. (Using transport tanks and colored water).

3. Observe a Gemini type water separator experiment in Mercury or HOPE capsule if adequate instrumentation is available.

4. Scale up a pore study experiment to the degree that behavior of water in the pore could be observed during zero gravity. This might be accomplished if the scale-up is made such that the Bond Number remains the same as in the fuel cell catalyst electrode structure.

APPENDIX I

LITERATURE REFERENCES

1. "Hydrodynamic considerations for the design of systems for very low gravity environments."
   William C. Reynolds, Lectures delivered at the Dept. Mech. Engr., Thermosciences Division, Stanford Univ., Stanford, California.

2. "Liquid-Behavior in a zero-G Field" by Ta Li, IAS Paper 61-20, New York, January, 1961.

3. NASA Technical Note D-1197 by D.A. Petrash, Robert F. Zappa, Edward W. Otto.

4. ASD Technical Note 61-84 by R.G. Clodfelter and Roger C. Lewis.

5. Technical Report No. ASD-TDR-62-19, 18 January 1962, General Electric Co., MSVD Dept.

6. R. Siegel and C. Usiskin, Trans. ASME, 81, 230 (1959).

7. R. Truseler and R.A. Clodfelter, Journal JAE, page 56, September, 1960.

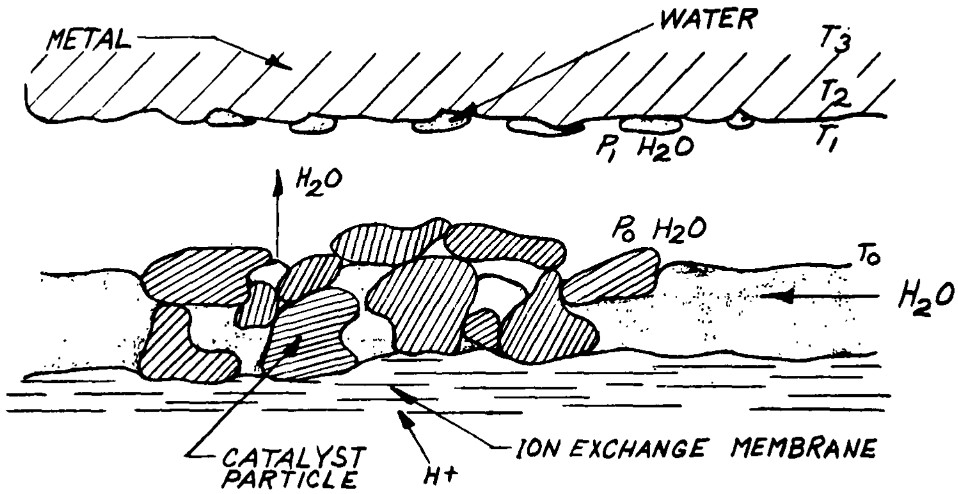


FIGURE 1 – SCHEMATIC REPRESENTATION OF ELECTROLYTE-ELECTRODE INTERFACE

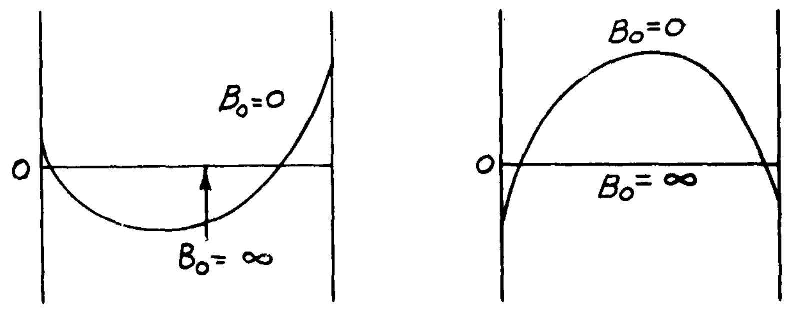


FIGURE 2 - REPRESENTATION OF MENISCUS GEOMETRY FOR VARIABLE BOND NUMBERS – B_0

APPENDIX II

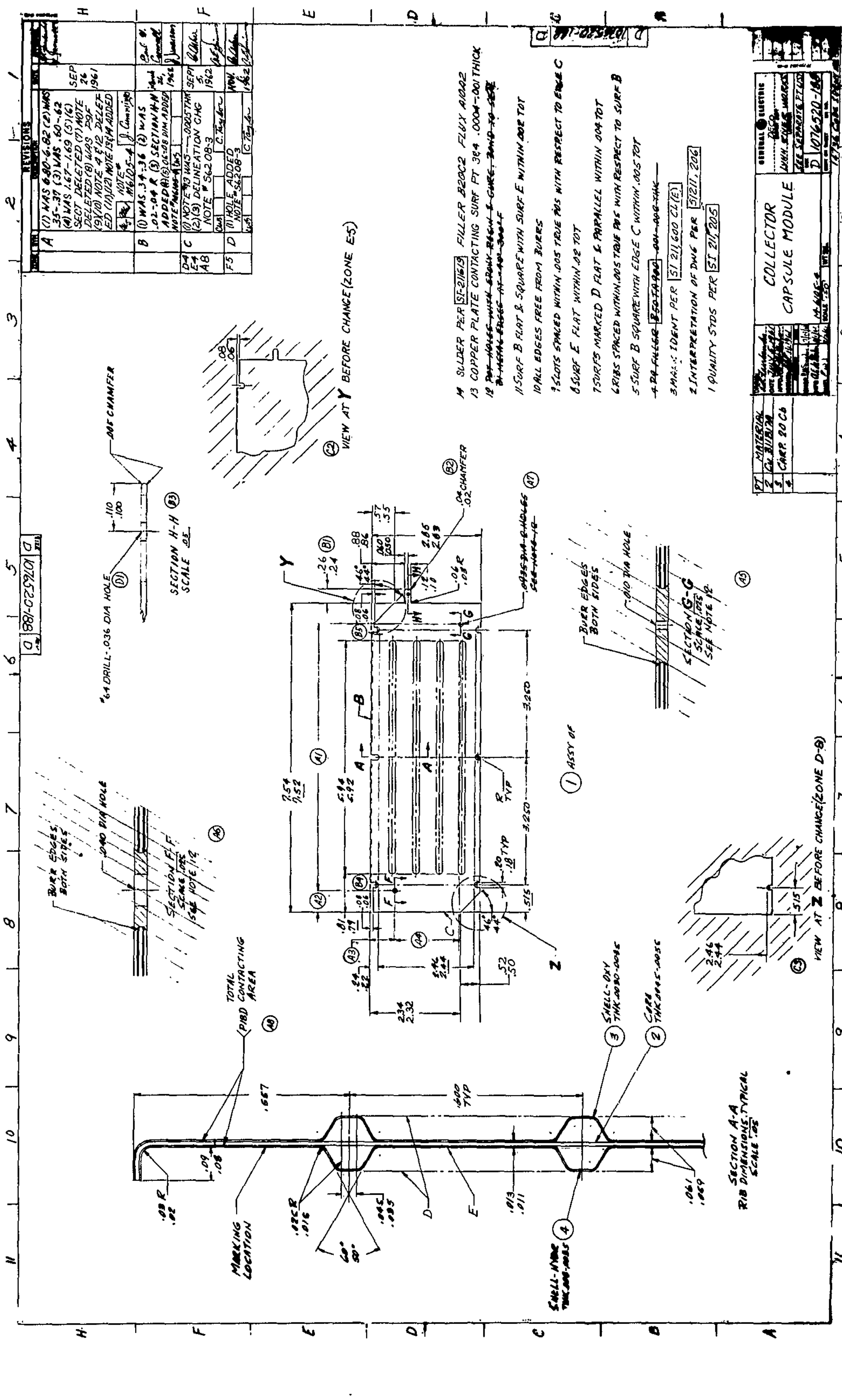
APPENDIX 1-K

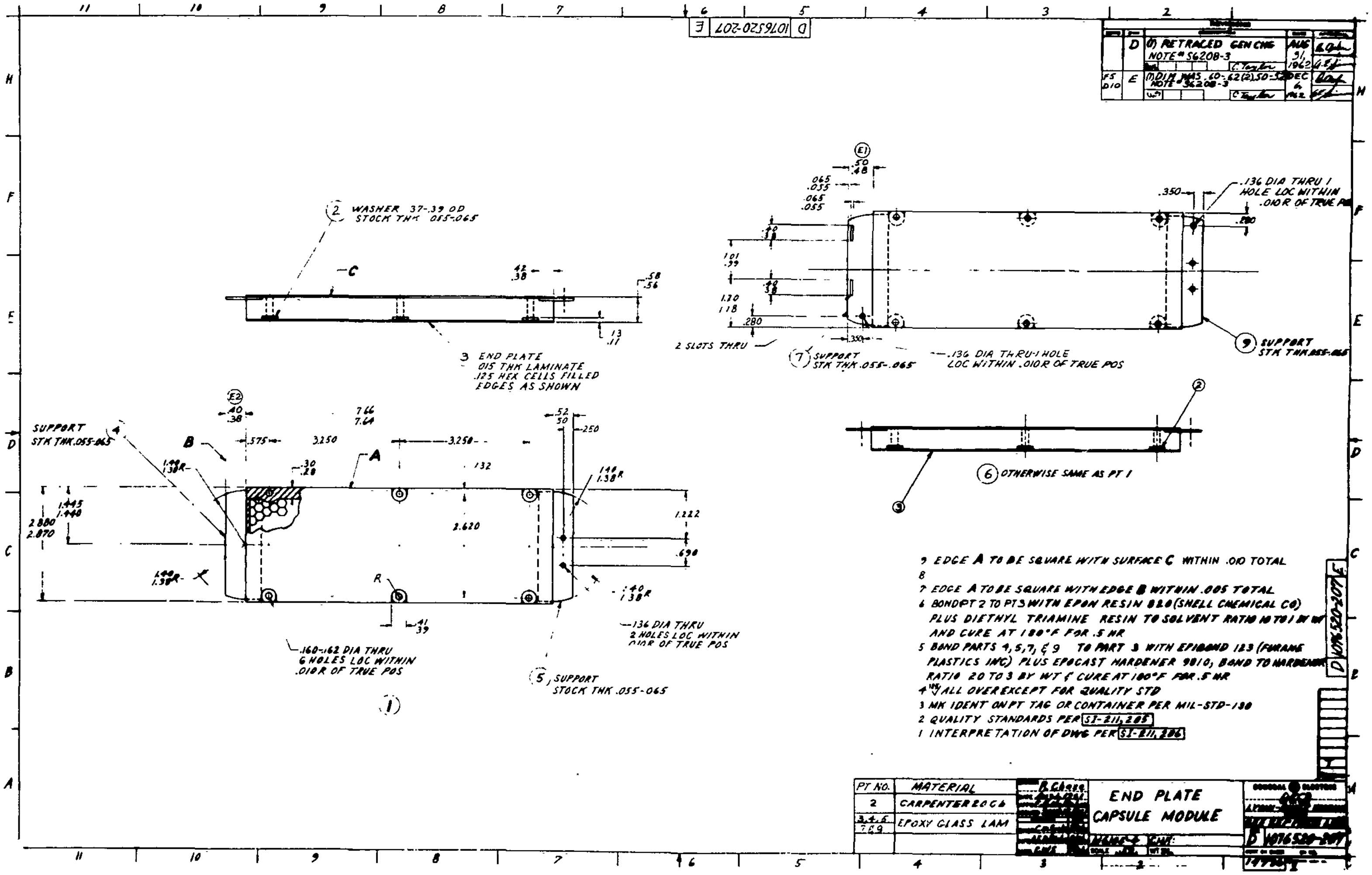
FUEL CELL SUBSYSTEM DRAWINGS (SELECTED)

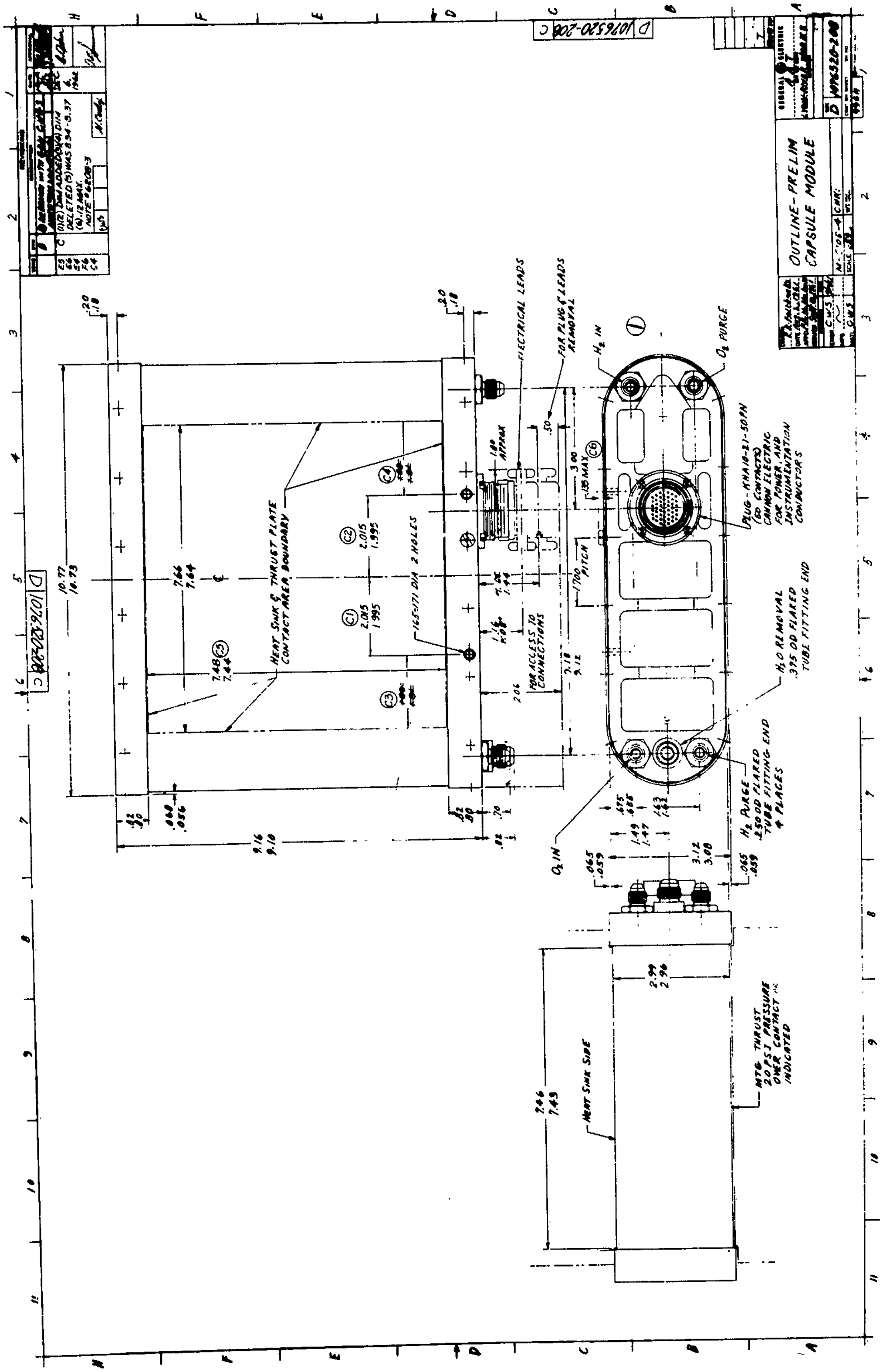
APPENDIX 1-K

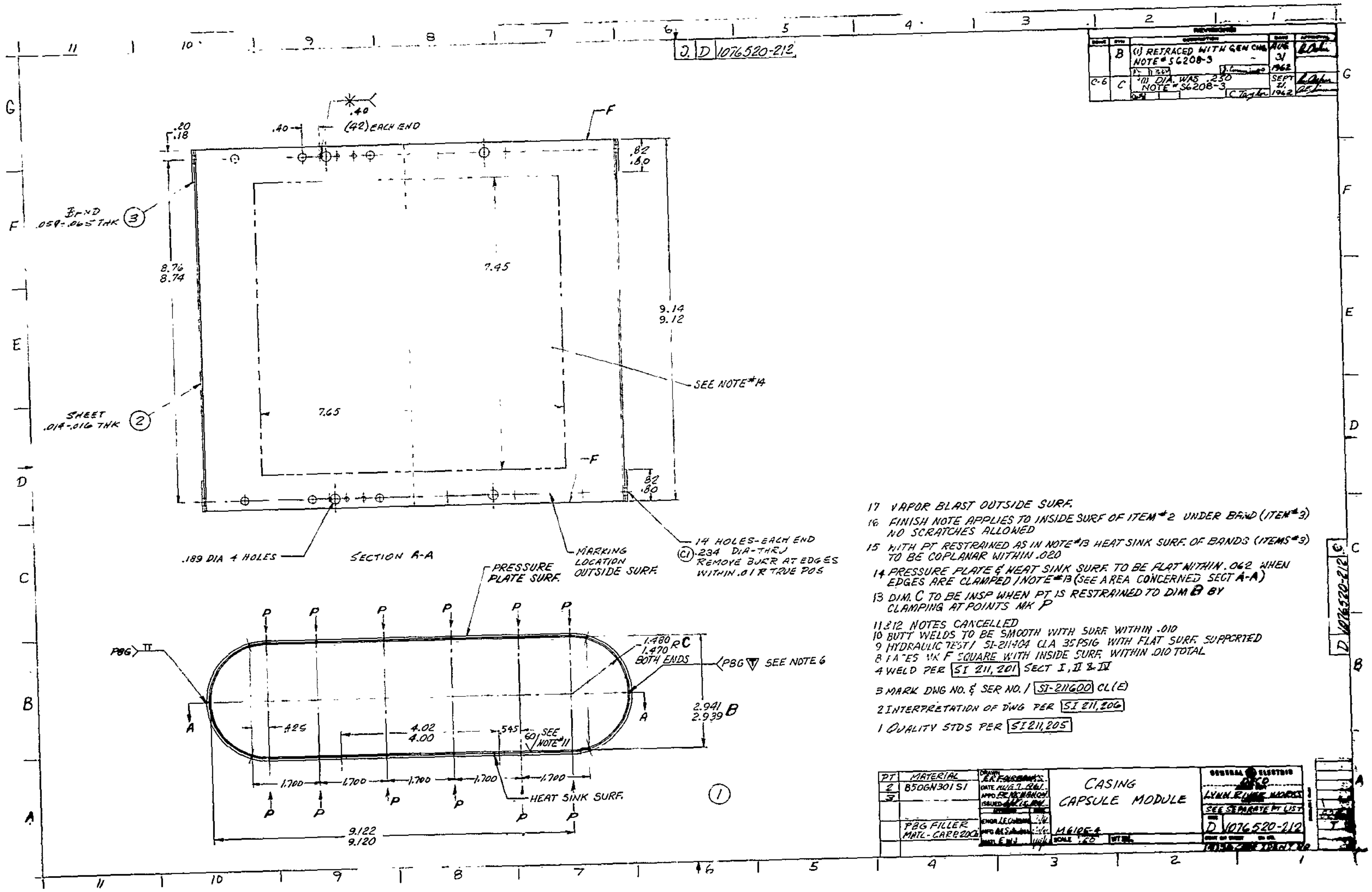
FUEL CELL SUBSYSTEM DRAWINGS (SELECTED)

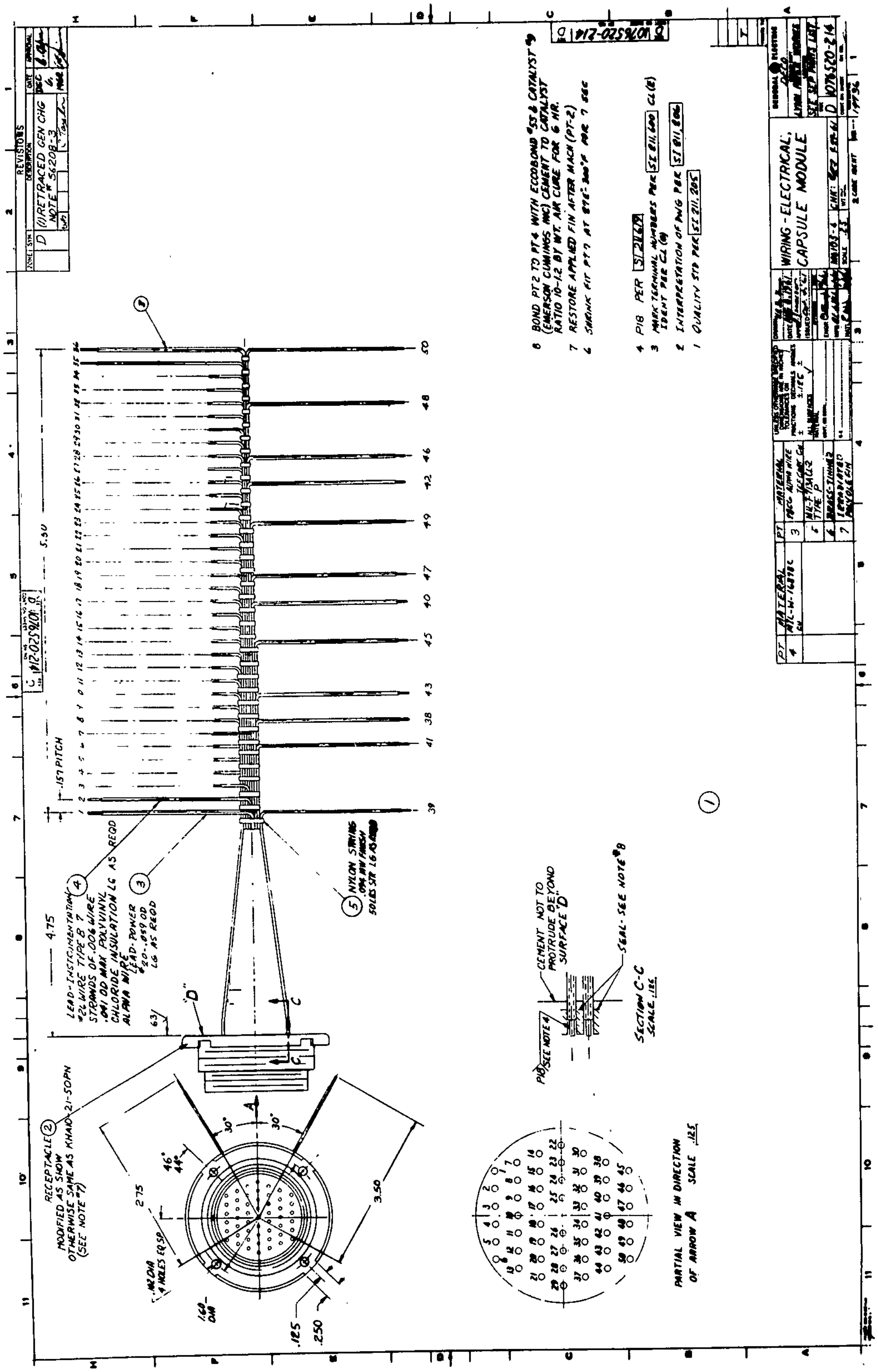
Drawing Number	Drawing Title
1076520-188	Collector - Capsule Module
1076520-207	End Plate - Capsule Module
1076520-208	Outline - Preliminary - Capsule Module
1076520-212	Casing - Capsule Module
1076520-214	Wiring - Electrical, Capsule Module
1076520-216	Cell Assembly - Capsule Module
1076520-218	Terminal Plate - Capsule Module
1076520-226	Module Assembly - Capsule
1076520-265	Module Assembly - Aerospace Capsule
1076520-266	Tank Assembly - Water Collector, Wadd Fuel Cell
1076520-267	Frame - Capsule Module
1076520-299	Tank - Water Collector, Wadd Fuel Cell
1076520-350	Mask - Hydrogen
1076520-390	Transport Wick
1076520-391	Cover - Capsule Module
1076520-392	Cover Assembly - Capsule Module
1076520-395	Cover-Casing, Capsule Module
1076520-399	Plate-Wick and Plate-Pressure
1076524-94	Wick Disconnect Assembly
1076524-127	Outline-Tank, Collector, Wadd Fuel Cell


COLLECTOR
CAPSULE MODULE
14 SOLDER PER 51-21615 FILLER B20C2 FLUX A1002
13 COPPER PLATE CONTACTING SURF PT 3&4 .0004-.001 THICK
11 SURF B FLAT & SQUARE WITH SURF E WITHIN .002 TOT
10 ALL EDGES FREE FROM BURRS
9 SLOTS SPACED WITHIN .005 TRUE POS WITH RESPECT TO EDGE C
8 SURF E FLAT WITHIN .02 TOT
7 SURFS MARKED D FLAT & PARALLEL WITHIN .004 TOT
6 RIBS SPACED WITHIN .005 TRUE POS WITH RESPECT TO SURF B
5 SURF B SQUARE WITH EDGE C WITHIN .005 TOT
3 MARK IDENT PER 51 21,600 CL(E)
2 INTERPRETATION OF DWG PER 51 21,206
1 QUALITY STDS PER 51 21,205
SECTION A-A
SECTION G-G
SECTION F-F
SECTION H-H
VIEW AT Y BEFORE CHANGE (ZONE E5)
VIEW AT Z BEFORE CHANGE (ZONE D-9)


D 1076520-207 E
D (1) RETRACED GEN CHG NOTE # 5620B-3
E (1) DIM WAS .60-.62 (2) .50-.52 NOTE # 5620B-3
2 WASHER .37-.39 OD STOCK THK .055-.065
3 END PLATE .015 THK LAMINATE .125 HEX CELLS FILLED EDGES AS SHOWN
SUPPORT STK THK .055-.065
.160-.162 DIA THRU 6 HOLES LOC WITHIN .010 R OF TRUE POS
5 SUPPORT STOCK THK .055-.065
.136 DIA THRU 2 HOLES LOC WITHIN .010 R OF TRUE POS
.136 DIA THRU 1 HOLE LOC WITHIN .010 R OF TRUE POS
9 SUPPORT STK THK .055-.065
2 SLOTS THRU
7 SUPPORT STK THK .055-.065
.136 DIA THRU-1 HOLE LOC WITHIN .010 R OF TRUE POS
6 OTHERWISE SAME AS PT 1
9 EDGE A TO BE SQUARE WITH SURFACE C WITHIN .010 TOTAL
8
7 EDGE A TO BE SQUARE WITH EDGE B WITHIN .005 TOTAL
6 BOND PT 2 TO PT 3 WITH EPON RESIN 828 (SHELL CHEMICAL CO) PLUS DIETHYL TRIAMINE RESIN TO SOLVENT RATIO 10 TO 1 BY WT AND CURE AT 180°F FOR .5 HR
5 BOND PARTS 4, 5, 7, & 9 TO PART 3 WITH EPIBOND 123 (FURANE PLASTICS INC) PLUS EPOCAST HARDENER 9810, BOND TO HARDENER RATIO 20 TO 3 BY WT & CURE AT 180°F FOR .5 HR
4 ALL OVER EXCEPT FOR QUALITY STD
3 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130
2 QUALITY STANDARDS PER S1-211, 285
1 INTERPRETATION OF DWG PER S1-211, 286
PT NO. MATERIAL
2 CARPENTER 20 Cb
3,4,5,7,9 EPOXY GLASS LAM
END PLATE
CAPSULE MODULE
D 1076520-207

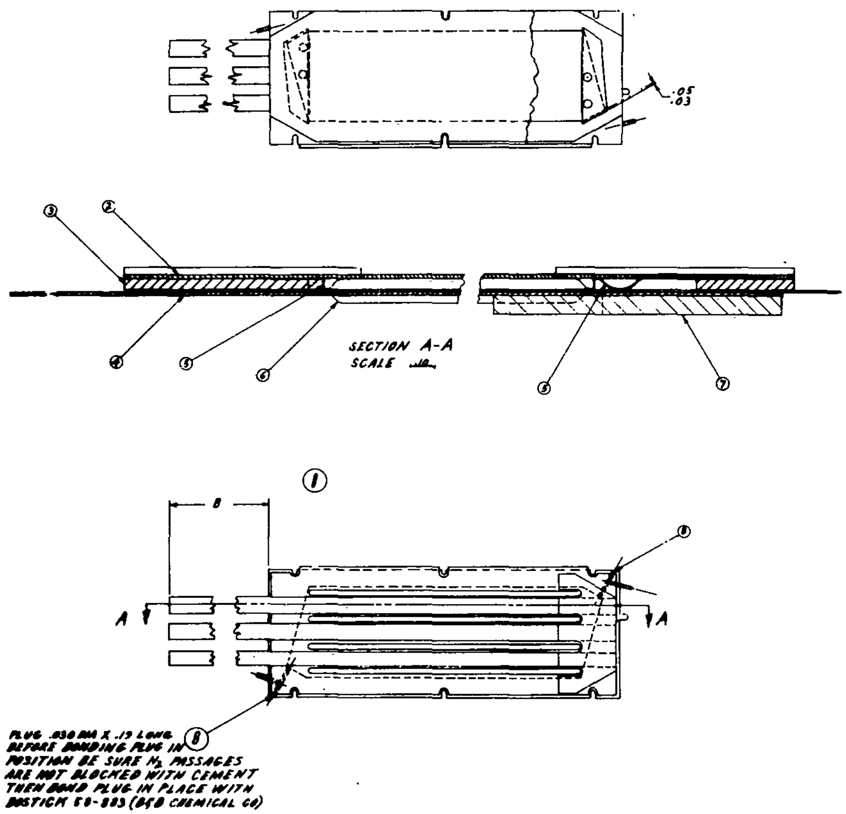

OUTLINE-PRELIM
CAPSULE MODULE
D 1076520-200 C
HEAT SINK & THRUST PLATE CONTACT AREA BOUNDARY
ELECTRICAL LEADS
FOR PLUG & LEADS REMOVAL
.165-.171 DIA 2 HOLES
FOR ACCESS TO CONNECTIONS
PITCH
PLUG-KHA10-21-50PN (60 CONTACTS) CANNON ELECTRIC FOR POWER, AND INSTRUMENTATION CONDUCTORS
H_2 IN
O_2 PURGE
H_2O REMOVAL .375 OD FLARED TUBE FITTING END
H_2 PURGE .250 OD FLARED TUBE FITTING END 4 PLACES
O_2 IN
HEAT SINK SIDE
MTG THRUST 20 PSI PRESSURE OVER CONTACT AREA INDICATED


B (1) RETRACED WITH GEN CHG NOTE # S6208-3 AUG 31 1962
C-6 C (1) DIA. WAS .230 NOTE # S6208-3 SEPT 21 1962
D 1076520-212
BAND .059-.065 THK (3)
SHEET .014-.016 THK (2)
(42) EACH END
SEE NOTE #14
.189 DIA 4 HOLES
SECTION A-A
MARKING LOCATION OUTSIDE SURF.
14 HOLES-EACH END (C1) .234 DIA-THRU REMOVE BURR AT EDGES WITHIN .01 R TRUE POS
PRESSURE PLATE SURF.
HEAT SINK SURF.
1.480 1.470 R C BOTH ENDS
PBG SEE NOTE 6
2.941 2.939 B
9.122 9.120
SEE NOTE #11
17 VAPOR BLAST OUTSIDE SURF.
16 FINISH NOTE APPLIES TO INSIDE SURF OF ITEM #2 UNDER BAND (ITEM #3) NO SCRATCHES ALLOWED
15 WITH PT RESTRAINED AS IN NOTE #13 HEAT SINK SURF. OF BANDS (ITEMS #3) TO BE COPLANAR WITHIN .020
14 PRESSURE PLATE & HEAT SINK SURF. TO BE FLAT WITHIN .062 WHEN EDGES ARE CLAMPED / NOTE #13 (SEE AREA CONCERNED SECT A-A)
13 DIM. C TO BE INSP WHEN PT IS RESTRAINED TO DIM B BY CLAMPING AT POINTS MK P
11 & 12 NOTES CANCELLED
10 BUTT WELDS TO BE SMOOTH WITH SURF. WITHIN .010
9 HYDRAULIC TEST / SI-211404 CLA 35 PSIG WITH FLAT SURF. SUPPORTED
8 FACES MK F SQUARE WITH INSIDE SURF. WITHIN .010 TOTAL
4 WELD PER SI 211,201 SECT I, II & IV
3 MARK DWG NO. & SER NO. / SI-211600 CL(E)
2 INTERPRETATION OF DWG PER SI 211,206
1 QUALITY STDS PER SI 211,205
PT MATERIAL
2 850GN301 S1
3
PBG FILLER MATL-CAP2002
CASING CAPSULE MODULE
GENERAL ELECTRIC
LYNN RIVER WORKS
SEE SEPARATE PT LIST
D 1076520-212
M6108-4



REVISIONS
D (1)RETRACED GEN CHG NOTE# 56208-3
5.30
.157 PITCH
4.75
LEAD-POWER #20-.059 OD LG AS REQD
NYLON STRING
RECEPTACLE MODIFIED AS SHOW OTHERWISE SAME AS KHAD-21-50PN (SEE NOTE #7)
CEMENT NOT TO PROTRUDE BEYOND SURFACE "D"
SEAL-SEE NOTE #8
SECTION C-C
PARTIAL VIEW IN DIRECTION OF ARROW A
3.50
2.75
.125
.250
8 BOND PT2 TO PT4 WITH ECCOBOND #55 & CATALYST #9 (EMERSON CUMINGS INC) CEMENT TO CATALYST RATIO 10-1.2 BY WT. AIR CURE FOR 6 HR.
7 RESTORE APPLIED FIN AFTER MACH (PT-2)
WIRING-ELECTRICAL, CAPSULE MODULE
10765520-214

D 1076520-216 B



B	REDRAWN ENG CHANGES NOTE # MLIOE-4		

11 BOND ITEM #7 TO ITEM #4 WITH BOSTICK & CURE FOR .5 HR AT ROOM TEMP

10 USE FOLLOWING PROCEDURE FOR BONDING ITEM #4 TO ITEM #6
- A: APPLY ONE HEAVY COAT OF BOSTICK IN .06 WIDE STRIPES TO ITEM #6 TO ALLOW FOR BONDING THE TWO EDGES OF ITEM #4 TO ITEM #6
- B: STRETCH ITEM #4 UNTIL TAUT AND PRESS IN PLACE BETWEEN RIBS OF ITEM #6 HOLD IN PLACE AND CURE AT ROOM TEMP FOR 4 HRS

9 USE FOLLOWING PROCEDURE FOR BONDING ITEM #5 TO ITEM #3
- A: SAND BOND SURFACE OF MASK ITEM #5 TO ROUGHEN
- B: APPLY ONE COAT OF BOSTICK ON BOND SURFACES OF ITEM #5 AND CURE FOR .5 HR AT 200°F ALSO APPLY ONE COAT OF BOSTICK ON MATING SUR OF ITEM #3 & LET DRY FOR 15 MIN
- C: APPLY SECOND COAT OF BOSTICK TO BOTH SURFACES AND PRESS TOGETHER AND LET DRY FOR 15 MIN

8 USE FOLLOWING PROCEDURE FOR BONDING ITEM #2 TO ITEM #3
- A: SAND NON-CATALYST BORDER OF CELL ITEM #2 TO ROUGHEN
- B: APPLY ONE EVEN COAT OF BOSTICK TO THE BOND SURFACE OF CELL ITEM #2 & FRAME ITEM #3 & ALLOW TO DRY FOR AT LEAST 15 MIN
- C: APPLY A SECOND COAT OF BOSTICK TO BOTH SURFACES, PRESS TOGETHER, & CURE IN HOLDING FIXTURE FOR 20 HRS

7 USE FOLLOWING PROCEDURE FOR BONDING ITEM #6 TO ITEM #3
- A: APPLY THIN EVEN COAT OF PLASTILOCK 604 (BF GOODRICH) TO ITEM #6 ON BONDING SURFACE. CURE FOR .5 HR AT 200°F AND THEN FOR .5 HR AT 350°F
- B: SAND THE PLASTILOCK SURFACE TO ROUGHEN
- C: APPLY ONE COAT OF BOSTICK TO THE ROUGHENED PLASTILOCK AND ALSO TO THE BOND SUR OF ITEM #3 LET DRY FOR 15 MIN
- D: APPLY SECOND COAT OF BOSTICK TO THESE SAME SUR PRESS SURFACES TOGETHER & HOLD IN FIXTURE & CURE FOR 20 HRS

6 PREPARE COLLECTOR ITEM #6 SURFACE TO BE BONDED BY DEGREASING WITH EITHER NITRIC ACID OR HOT PICKLE OR ACETONE. THEN WASH WITH EITHER DIVERSEY 808 OR ALCONOX AND RINSE WITH DISTILLED WATER. SAND TO ROUGHEN

5 PREPARE FRAME ITEM #3 SURFACES TO BE BONDED BY SANDING TO ROUGHEN AND DEGREASING WITH SOLVENT

4 HANDLING INSTRUCTIONS FOR CELL ITEM #2
- A: DO NOT CONTACT COATED SURFACES OR CELL EDGES WITH ANY MATL OTHER THAN CLEAN POLYETHYLENE BAGGING AND GLOVES, DISTILLED WATER AND CLEAN COLLECTOR ASSEMBLIES
- B: DO NOT ALLOW COLLECTOR ASSEMBLIES TO SCRATCH OR SLIDE ACROSS COATED SURFACE OF CELL

3 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130

2 QUALITY STANDARDS PER SI-211,205

1 INTERPRETATION OF DWG PER SI-211,206

D 1076520-216 B

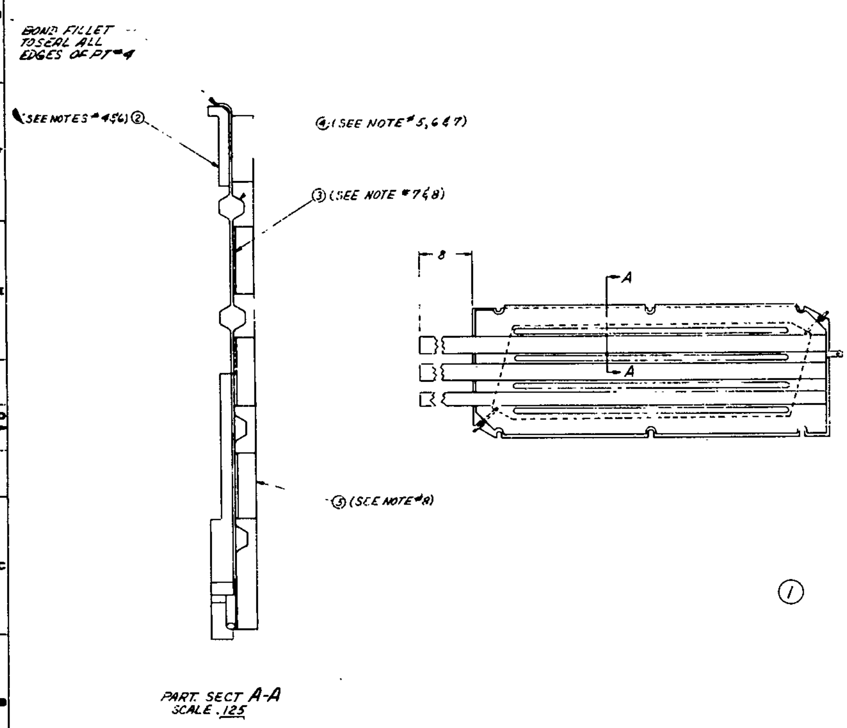
PART	MATERIAL
8	NI-O-NEL

CELL ASSEMBLY
CAPSULE MODULE

GENERAL ELECTRIC

D 1076520-216

ZONE	SYM	REVISIONS DESCRIPTION	DATE	APPROVAL
	C	(1) RETRACED-GEN CHG NOTE # S6208-3	SEPT 21, 1962	



PART SECT A-A
SCALE .125

8. BOND ITEM #5 TO ITEM #3 WITH BOSTICK & CURE FOR .5 HR AT ROOM TEMP.
7. USE FOLLOWING PROCEDURE FOR BONDING ITEMS 3 & 4
   A: APPLY ONE HEAVY COAT OF BOSTICK IN .06 WIDE STRIPES TO ITEM #4 TO ALLOW FOR BONDING THE 2 EDGES OF ITEM 3 TO ITEM 4
   B: STRETCH ITEM #3 UNTILL TAUT & PRESS IN PLACE BETWEEN RIBS OF ITEM #4 HOLD IN PLACE & CURE AT ROOM TEMP FOR 4 HR.
6. USE FOLLOWING PROCEDURE FOR BONDING ITEMS 2 & 4
   A: APPLY THIN EVEN COAT OF PLASTICLOCK 604 (BF GOODRICH) TO ITEM #4 ON BONDING SURF. CURE FOR .5 HR AT 200°F & THEN FOR .5 HR AT 350°F
   B: SAND THE PLASTICLOCK SURF. TO ROUGHEN
   C: APPLY ONE COAT OF BOSTICK TO ROUGHENED PLASTIC-LOCK & BOND. SURF ITEM #2. LET DRY FOR 15 MIN.
   D: APPLY 2ND COAT OF BOSTICK TO SAME SURF., PRESS SURF. TOGETHER, FIXTURE & CURE FOR 20 MIN.
5. PREPARE ITEM #4 SURF TO BE BONDED BY DEGREASE WITH NITRIC ACID, HOT PICKLE OR ACETONE. WASH WITH EITHER DIVERSEY 808 OR ALCONO, RINSE WITH DISTILLED WATER. SAND & DUST
4. PREPARE ITEM #2 SURF. TO BE BONDED BY DEGREASE & SLIGHTLY SOFTENING WITH TOLUENE, ROUGHEN SURF BY SANDING & DUST.
3. MK IDENT ON PT TAG OR CONTAINER / MIL-STD-130
2. QUAL STD / SI-211205
1. INTERPRETATION OF DWG / SI-211206

C 1076520-218

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON FRACTIONS ± DECIMALS ± ANGLES ±
ALL SURFACES √
MATERIAL FOR PT #6

DRAWN J. Cummings. DATE AUG. 30, 1961
APPD F. McMAHON
ISSUED SEP. 11, 1961
ENGR C.M.S.
MFG A.E.D.S.
MATL C.H.S.

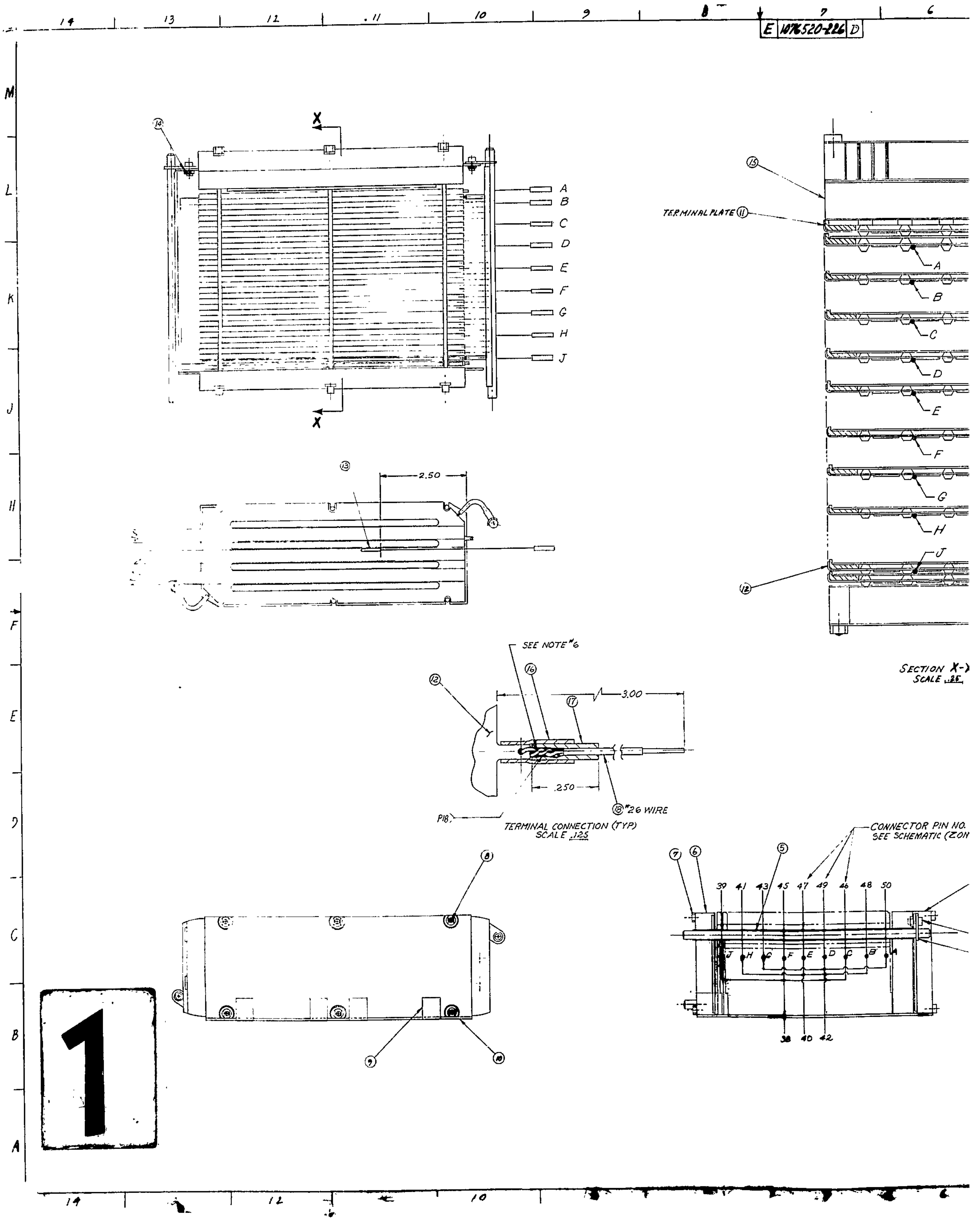
TERMINAL PLATE
CAPSULE MODULE

GENERAL ELECTRIC
DECO
LYNN RIVER WORKS
SEE SEP PTS LIST

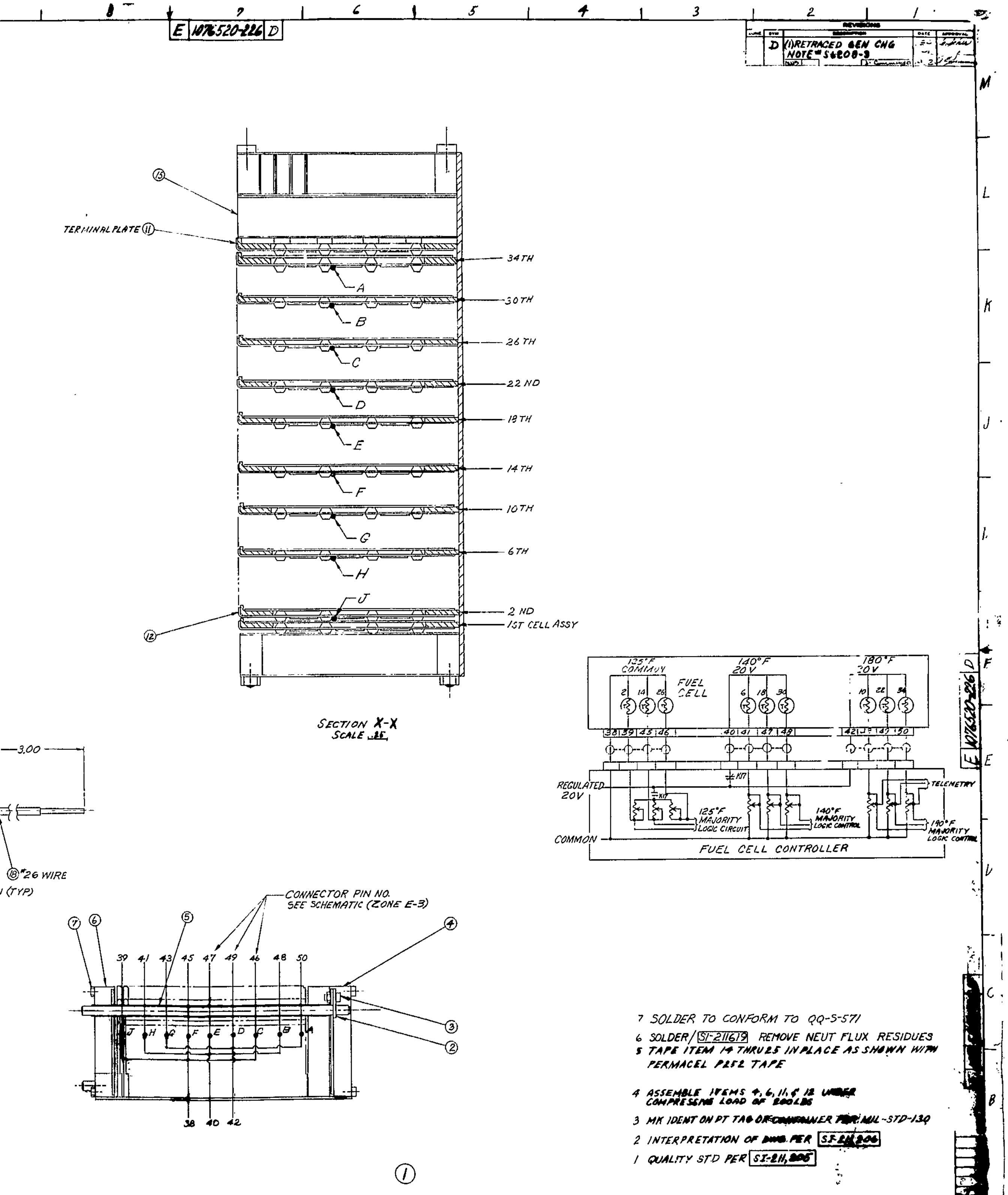
MG105-4 | E.R.F. 8-29-61 | SCALE .50

D 1076520-218

14736



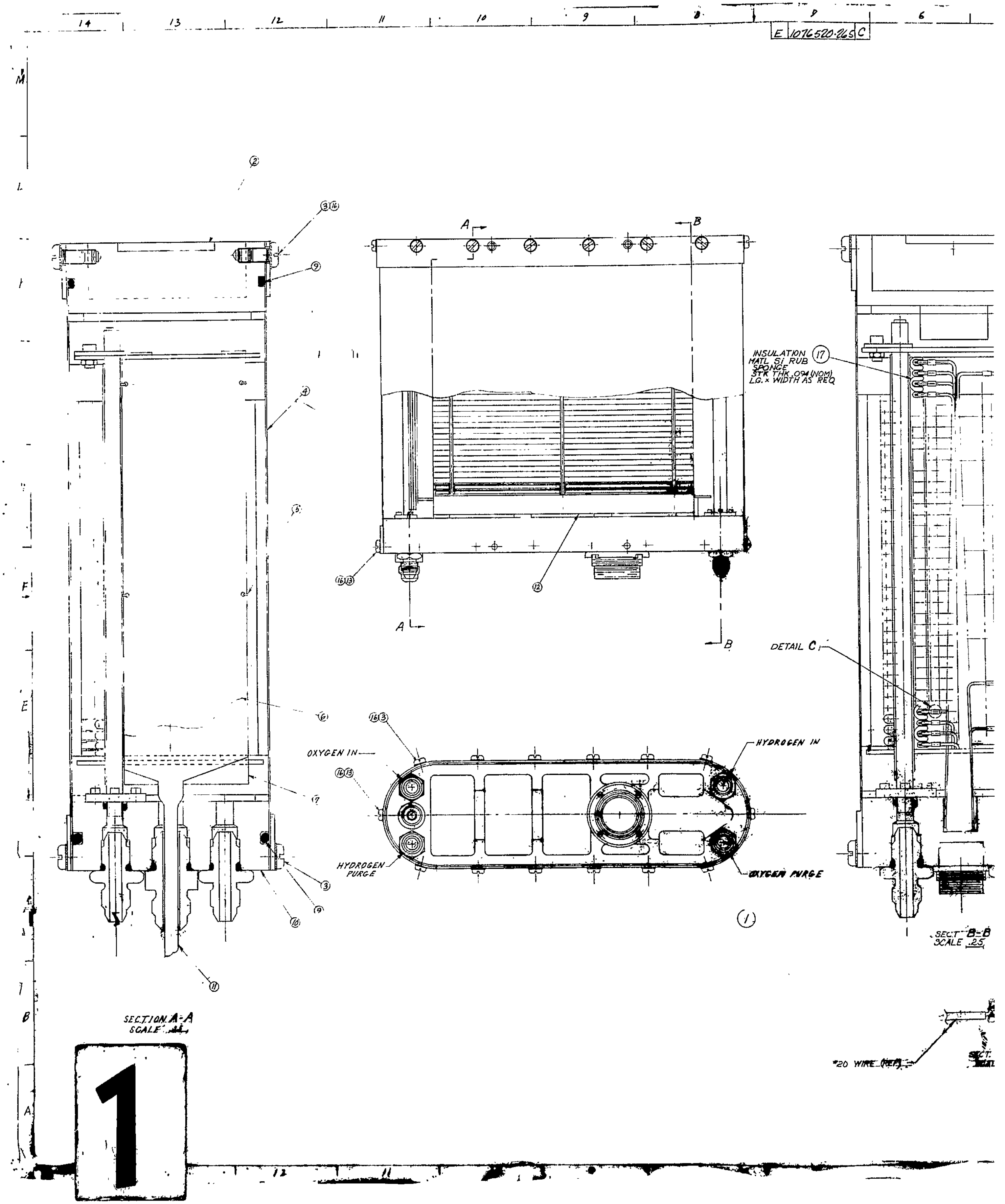
E 1076520-226 D
TERMINAL PLATE ⑪
SEE NOTE #6
3.00
.250
⑱ #26 WIRE
TERMINAL CONNECTION (TYP)
SCALE .125
SECTION X-X
SCALE .25
CONNECTOR PIN NO.
SEE SCHEMATIC (ZON
2.50
A
B
C
D
E
F
G
H
J
39 41 43 45 47 49 46 48 50
38 40 42
1



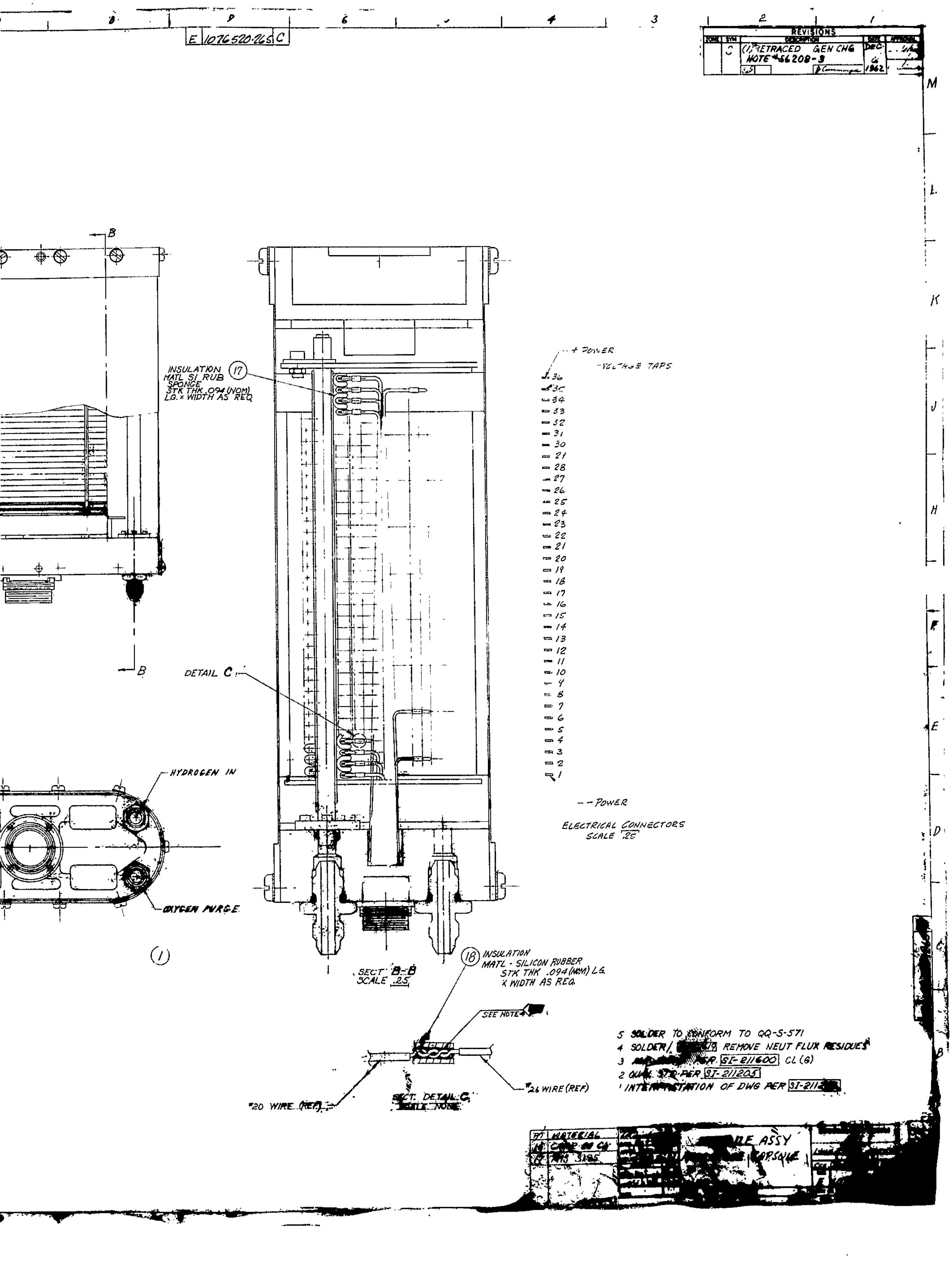
7 SOLDER TO CONFORM TO QQ-S-571
6 SOLDER/SI-211619 REMOVE NEUT FLUX RESIDUES
5 TAPE ITEM 14 THRU 25 IN PLACE AS SHOWN WITH PERMACEL P252 TAPE
4 ASSEMBLE ITEMS 4, 6, 11, & 12 UNDER COMPRESSING LOAD OF 200 LBS
3 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130
2 INTERPRETATION OF DWG PER SI-211,206
1 QUALITY STD PER SI-211,205

MODULE ASSEMBLY CAPSULE

2



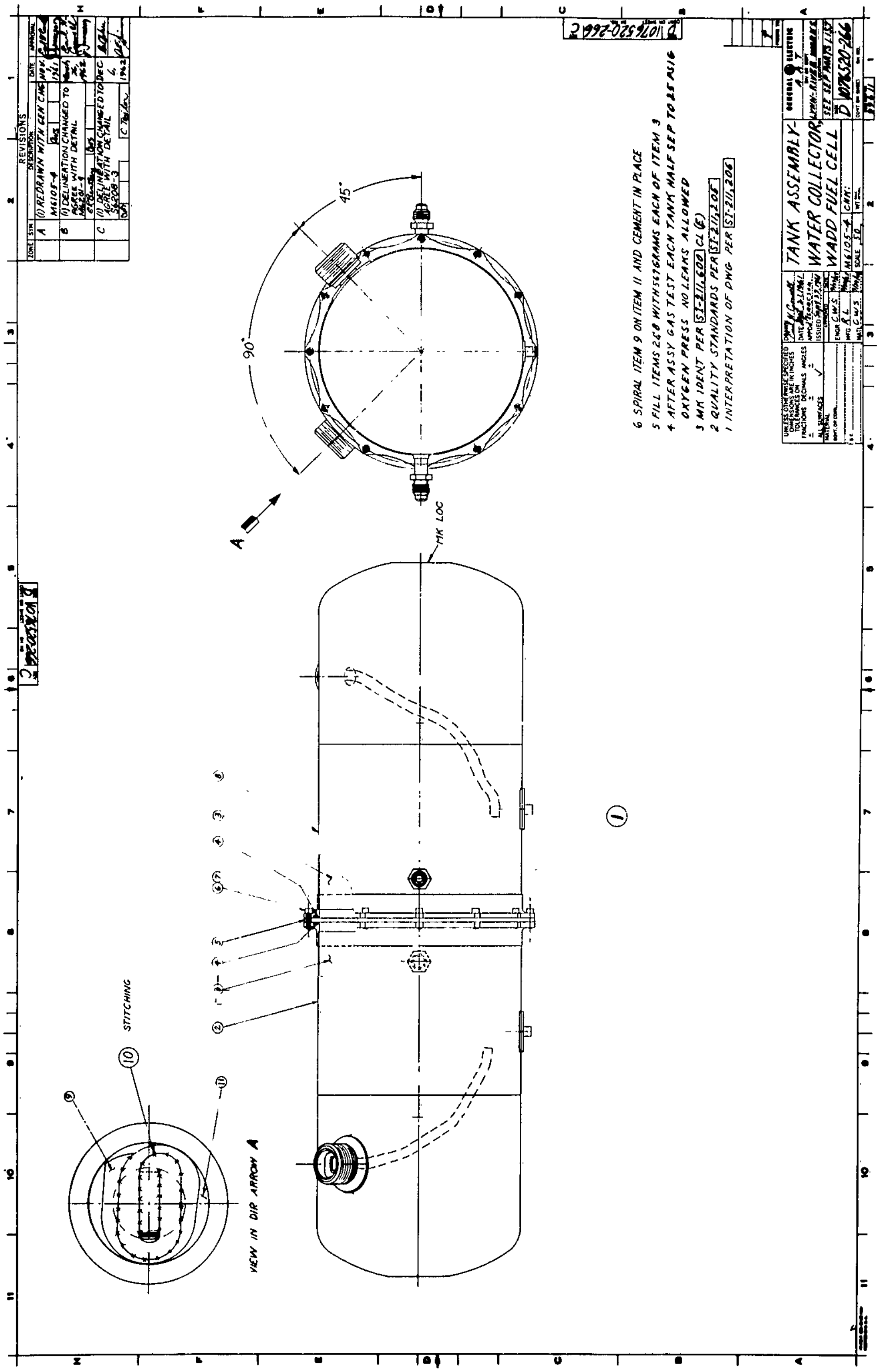
E 1076520-265 C
OXYGEN IN
HYDROGEN IN
HYDROGEN PURGE
OXYGEN PURGE
INSULATION (17) MATL SI RUB SPONGE STK THK .094 (NOM) LG. x WIDTH AS REQ
DETAIL C
SECTION A-A
SECT B-B SCALE .25
#20 WIRE (REF)
1



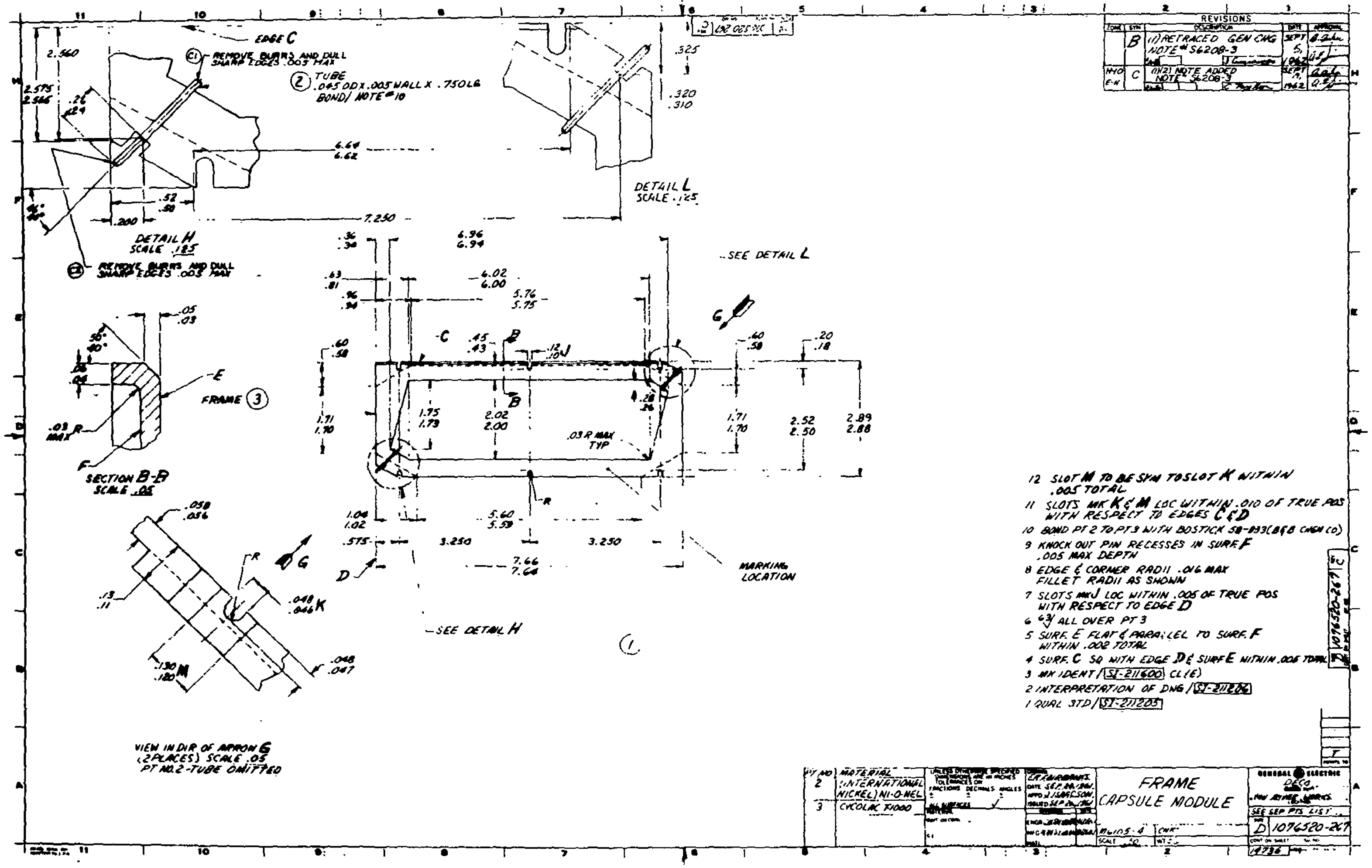
E 1076520-265 C
REVISIONS
C (1) RETRACED GEN CHG NOTE #56208-3
DEC 6 1962
M
L
K
J
H
F
E
D
C
B
B
B
INSULATION (17)
MATL SI RUB SPONGE
STK THK .094 (NOM)
LG. x WIDTH AS REQ
DETAIL C
HYDROGEN IN
OXYGEN PURGE
(1)
SECT B-B
SCALE .25
+ POWER
VOLTAGE TAPS
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
– POWER
ELECTRICAL CONNECTORS
SCALE .25
(18) INSULATION
MATL - SILICON RUBBER
STK THK .094 (NOM) LG.
x WIDTH AS REQ.
SEE NOTE 4
#20 WIRE (REF)
#26 WIRE (REF)
SECT. DETAIL C
SCALE NONE
5 SOLDER TO CONFORM TO QQ-S-571
4 SOLDER / REMOVE NEUT FLUX RESIDUES
3 PER SI-211600 CL (6)
2 QUAL STD PER SI-211205
1 INTERPRETATION OF DWG PER SI-211
MATERIAL
MS 3195
ASSY

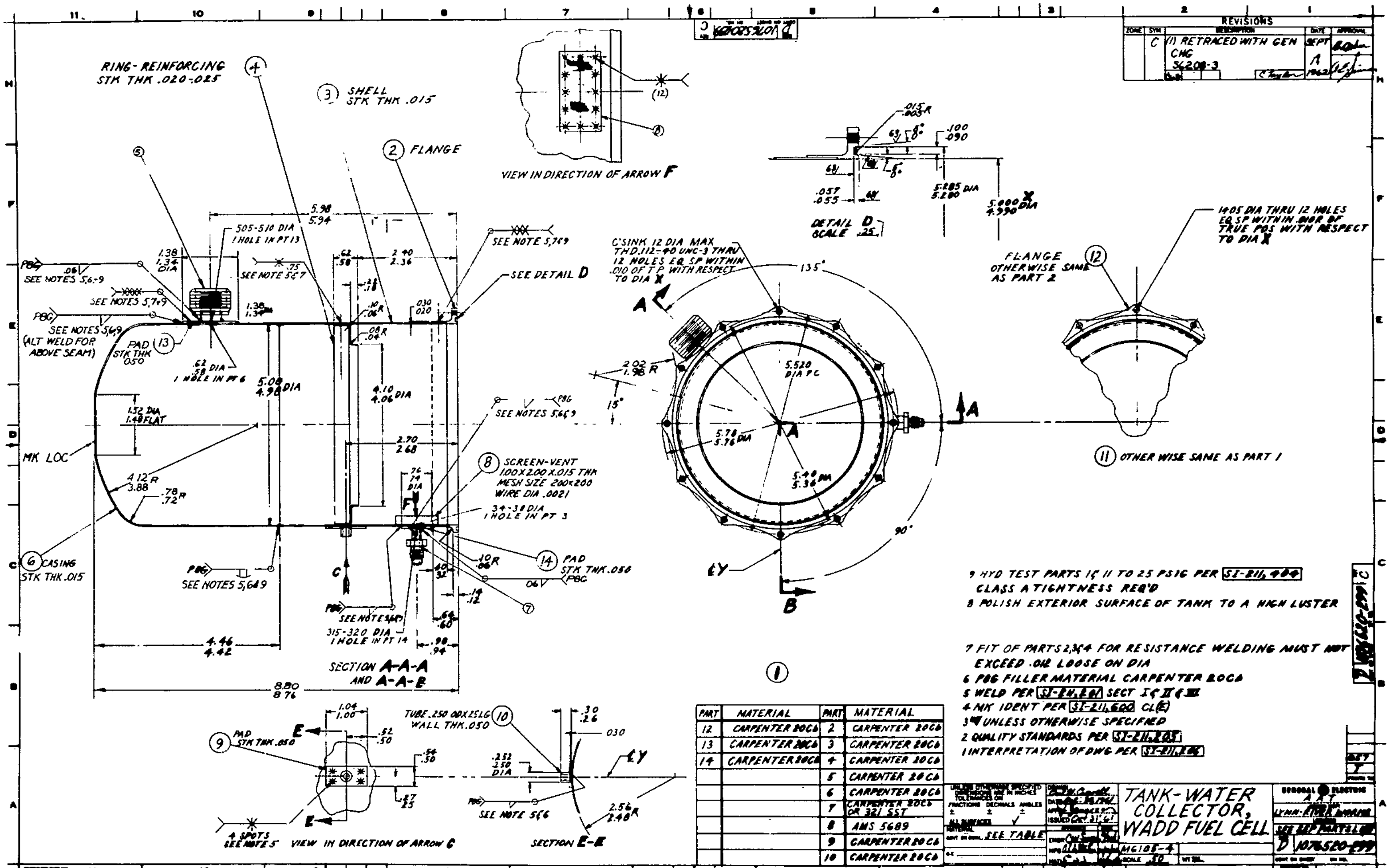
2

1K-11/1K-12

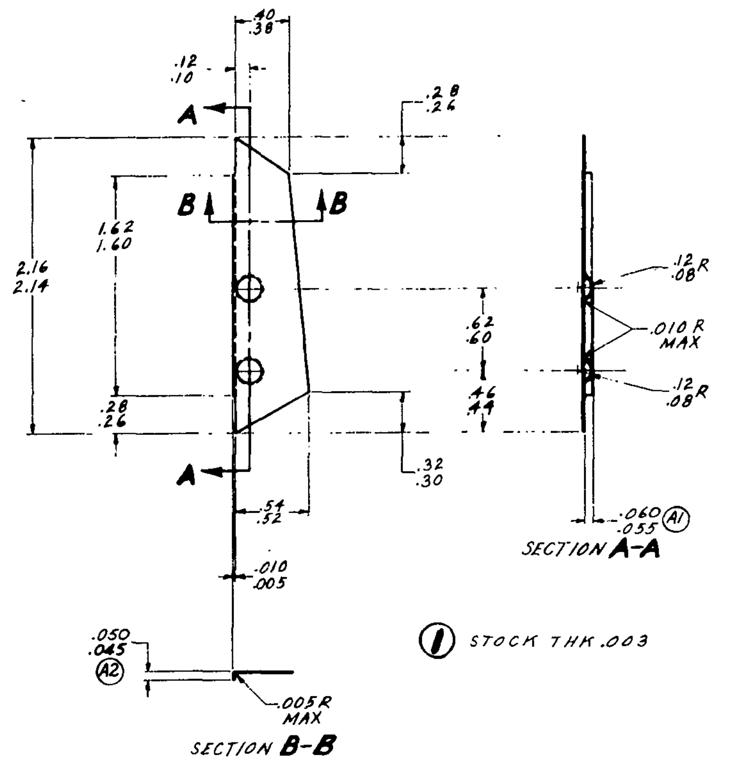


REVISIONS
A (1) REDRAWN WITH GEN CHG M6105-4
B (1) DELINEATION CHANGED TO AGREE WITH DETAIL
C (1) DELINEATION CHANGED TO AGREE WITH DETAIL
107R520-266 C
45°
90°
A
MK LOC
STITCHING
VIEW IN DIR ARROW A
6 SPIRAL ITEM 9 ON ITEM 11 AND CEMENT IN PLACE
5 FILL ITEMS 2 & 8 WITH 567 GRAMS EACH OF ITEM 3
4 AFTER ASSY GAS TEST EACH TANK HALF SEP TO 25 PSIG OXYGEN PRESS NO LEAKS ALLOWED
3 MK IDENT PER SI-211,600 CL (E)
2 QUALITY STANDARDS PER SI-211,205
1 INTERPRETATION OF DWG PER SI-211,206
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TANK ASSEMBLY-WATER COLLECTOR, WADD FUEL CELL
GENERAL ELECTRIC
SEE SEP PARTS LIST
D 107R520-266
M6105-4
SCALE 5/8


REVISIONS
B (1) RETRACED GEN CHG NOTE # S6208-3
C (1)(2) NOTE ADDED NOTE S6208-3
EDGE C
C1 REMOVE BURRS AND DULL SHARP EDGES .003 MAX
2 TUBE .045 OD X .005 WALL X .750 LG BOND/ NOTE #10
DETAIL H SCALE .125
REMOVE BURRS AND DULL SHARP EDGES .003 MAX
DETAIL L SCALE .125
SEE DETAIL L
SEE DETAIL H
SECTION B-B SCALE .05
FRAME 3
.03 R MAX TYP
MARKING LOCATION
VIEW IN DIR OF ARROW G (2 PLACES) SCALE .05 PT NO.2 - TUBE OMITTED
12 SLOT M TO BE SYM TO SLOT K WITHIN .005 TOTAL
11 SLOTS MK K & M LOC WITHIN .010 OF TRUE POS WITH RESPECT TO EDGES C & D
10 BOND PT 2 TO PT 3 WITH BOSTICK 58-893 (B&B CHEM CO)
9 KNOCK OUT PIN RECESSES IN SURF. F .005 MAX DEPTH
8 EDGE & CORNER RADII .016 MAX FILLET RADII AS SHOWN
7 SLOTS MK J LOC WITHIN .005 OF TRUE POS WITH RESPECT TO EDGE D
6 63 ALL OVER PT 3
5 SURF. E FLAT & PARALLEL TO SURF. F WITHIN .002 TOTAL
4 SURF. C SQ WITH EDGE D & SURF E WITHIN .005 TOTAL
3 MK IDENT / SI-211600 CL (E)
2 INTERPRETATION OF DWG / SI-211206
1 QUAL STD / SI-211205
PT NO MATERIAL
2 INTERNATIONAL NICKEL) NI-O-NEL
3 CYCOLAC F1000
FRAME
CAPSULE MODULE
GENERAL ELECTRIC
DECO
SEE SEP PTS LIST
D 1076520-267


REVISIONS
C (1) RETRACED WITH GEN CHG 54208-3
RING-REINFORCING STK THK .020-.025
SHELL STK THK .015
FLANGE
VIEW IN DIRECTION OF ARROW F
DETAIL D SCALE .25
FLANGE OTHERWISE SAME AS PART 2
.1405 DIA THRU 12 HOLES EQ SP WITHIN .010 OF TRUE POS WITH RESPECT TO DIA X
C'SINK .12 DIA MAX THD .112-40 UNC-3 THRU 12 HOLES EQ SP WITHIN .010 OF T P WITH RESPECT TO DIA X
OTHERWISE SAME AS PART 1
SEE NOTE 5,7&9
SEE DETAIL D
SEE NOTES 5,6&9
SCREEN-VENT 100X200X.015 THK MESH SIZE 200x200 WIRE DIA .0021
3/4-3/8 DIA 1 HOLE IN PT 3
PAD STK THK .050
MK LOC
CASING STK THK .015
SECTION A-A-A AND A-A-B
TUBE .250 ODX.25LG WALL THK .050
PAD STK THK .050
4 SPOTS SEE NOTE 5
VIEW IN DIRECTION OF ARROW C
SEE NOTE 5&6
SECTION E-E
9 HYD TEST PARTS 1 & 11 TO 25 PSIG PER SI-211,404
CLASS A TIGHTNESS REQ'D
8 POLISH EXTERIOR SURFACE OF TANK TO A HIGH LUSTER
7 FIT OF PARTS 2,3&4 FOR RESISTANCE WELDING MUST NOT EXCEED .012 LOOSE ON DIA
6 PBG FILLER MATERIAL CARPENTER 20CB
5 WELD PER SI-214,801 SECT I & II & III
4 MK IDENT PER SI-211,600 CL(E)
3 UNLESS OTHERWISE SPECIFIED
2 QUALITY STANDARDS PER SI-211,205
1 INTERPRETATION OF DWG PER SI-211,105
PART MATERIAL
12 CARPENTER 20CB
13 CARPENTER 20CB
14 CARPENTER 20CB
2 CARPENTER 20CB
3 CARPENTER 20CB
4 CARPENTER 20CB
5 CARPENTER 20CB
6 CARPENTER 20CB
7 CARPENTER 20CB OR 321 SST
8 AMS 5689
9 CARPENTER 20CB
10 CARPENTER 20CB
TANK-WATER COLLECTOR, WADD FUEL CELL
GENERAL ELECTRIC
SEE TABLE
MG108-4
SCALE .50

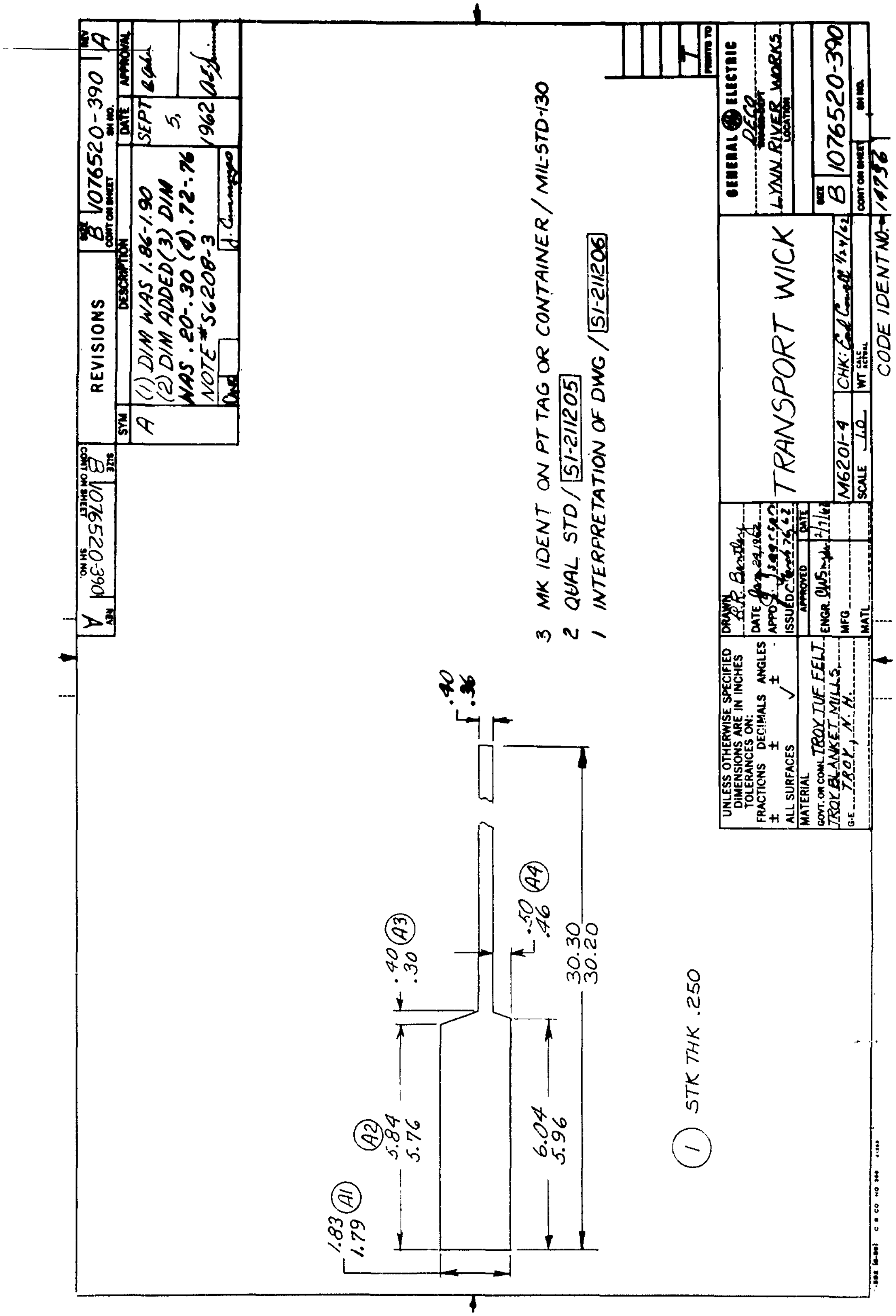
REVISIONS			SIZE C 1076520-350 SH NO	REV A
ZONE	SYM	DESCRIPTION	DATE	APPROVAL
C-4 B-7	A	(1) DIM WAS .055-.065 (2) .050-.060 NOTE * S6208-3 C Taylor	SEPT 14 1962	

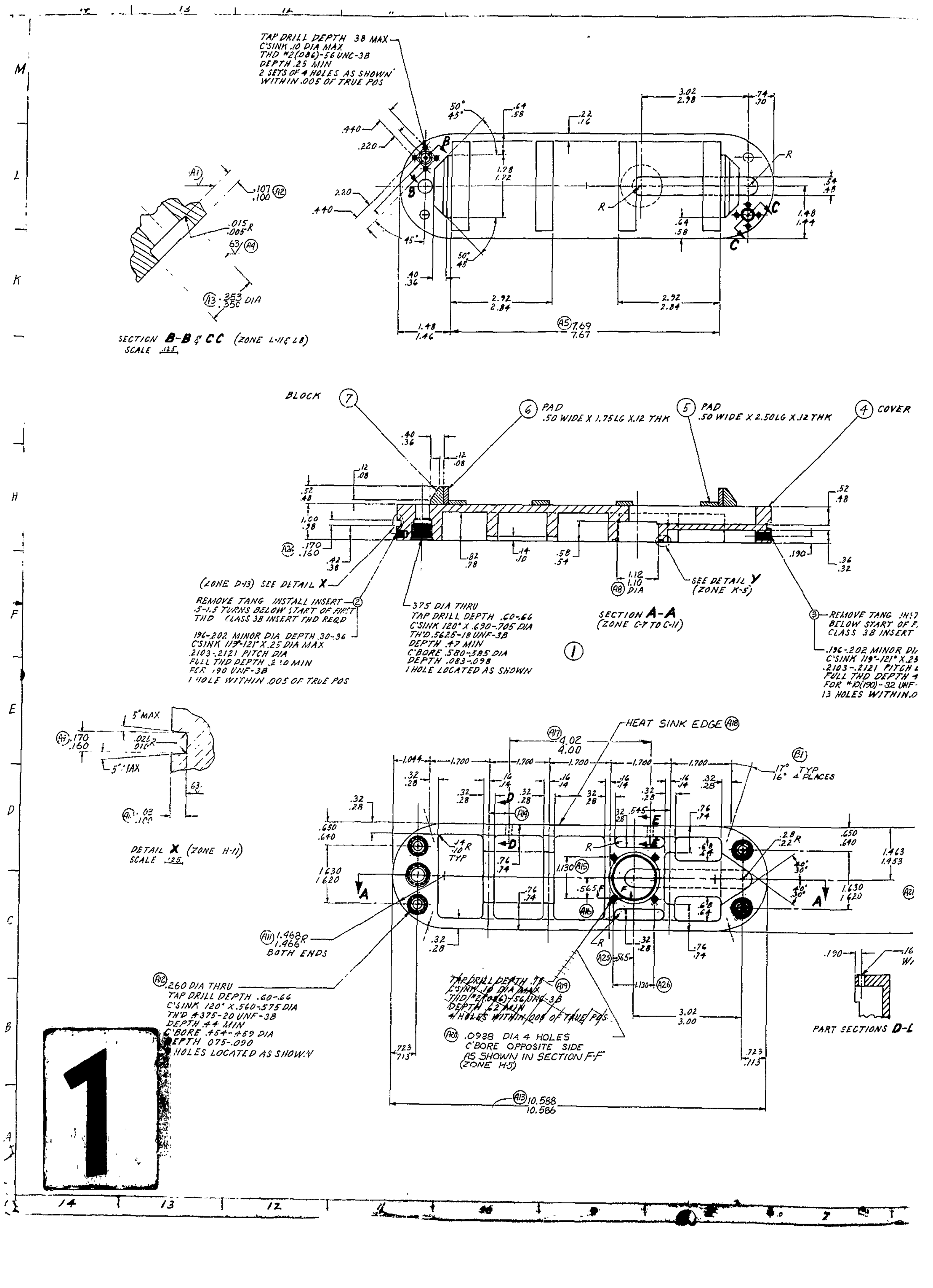


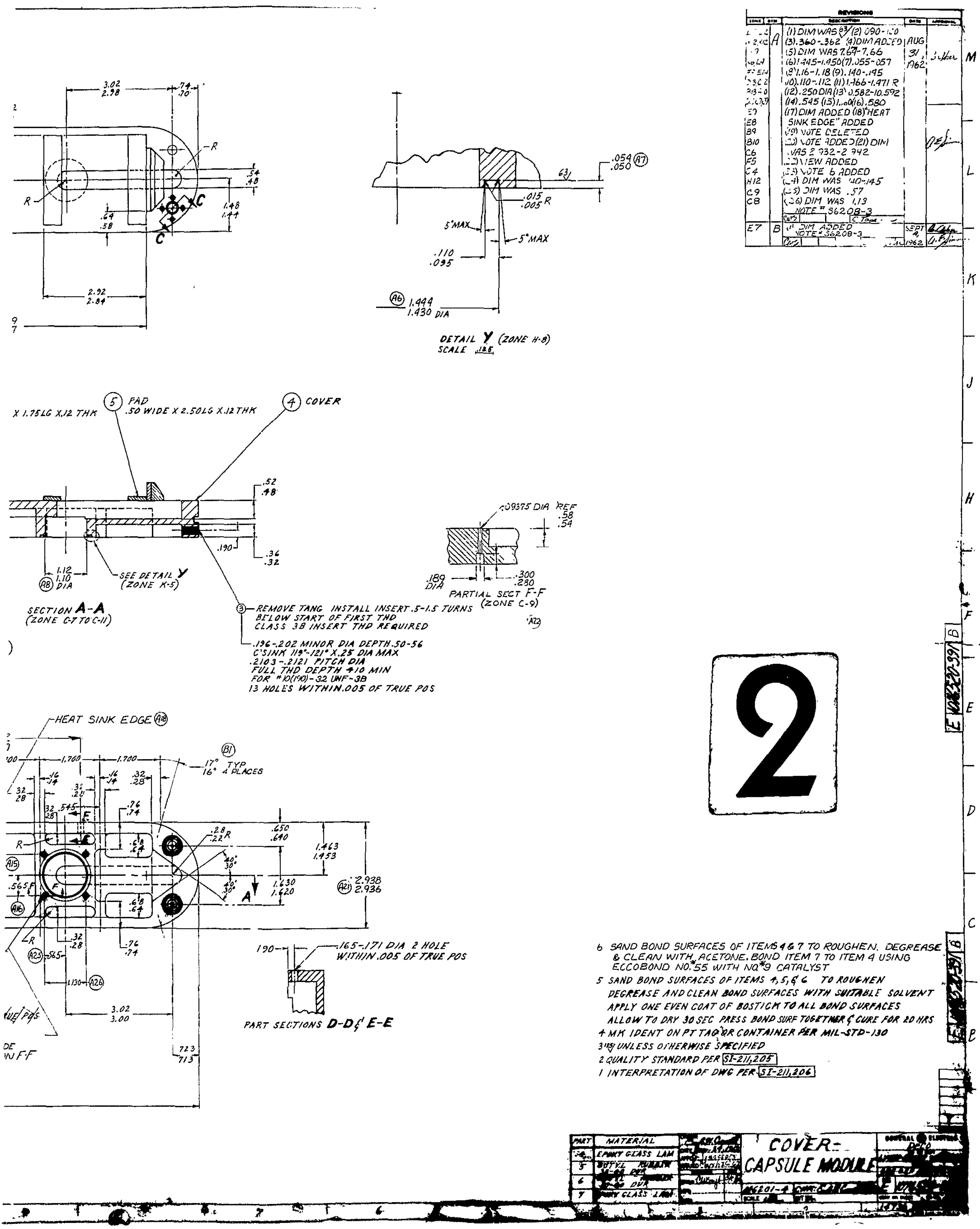
1 STOCK THK .003

4 ALL EDGES MUST BE FREE OF BURRS
3 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130
2 QUALITY STANDARDS PER SI-211,205
1 INTERPRETATION OF DWG PER SI-211,206

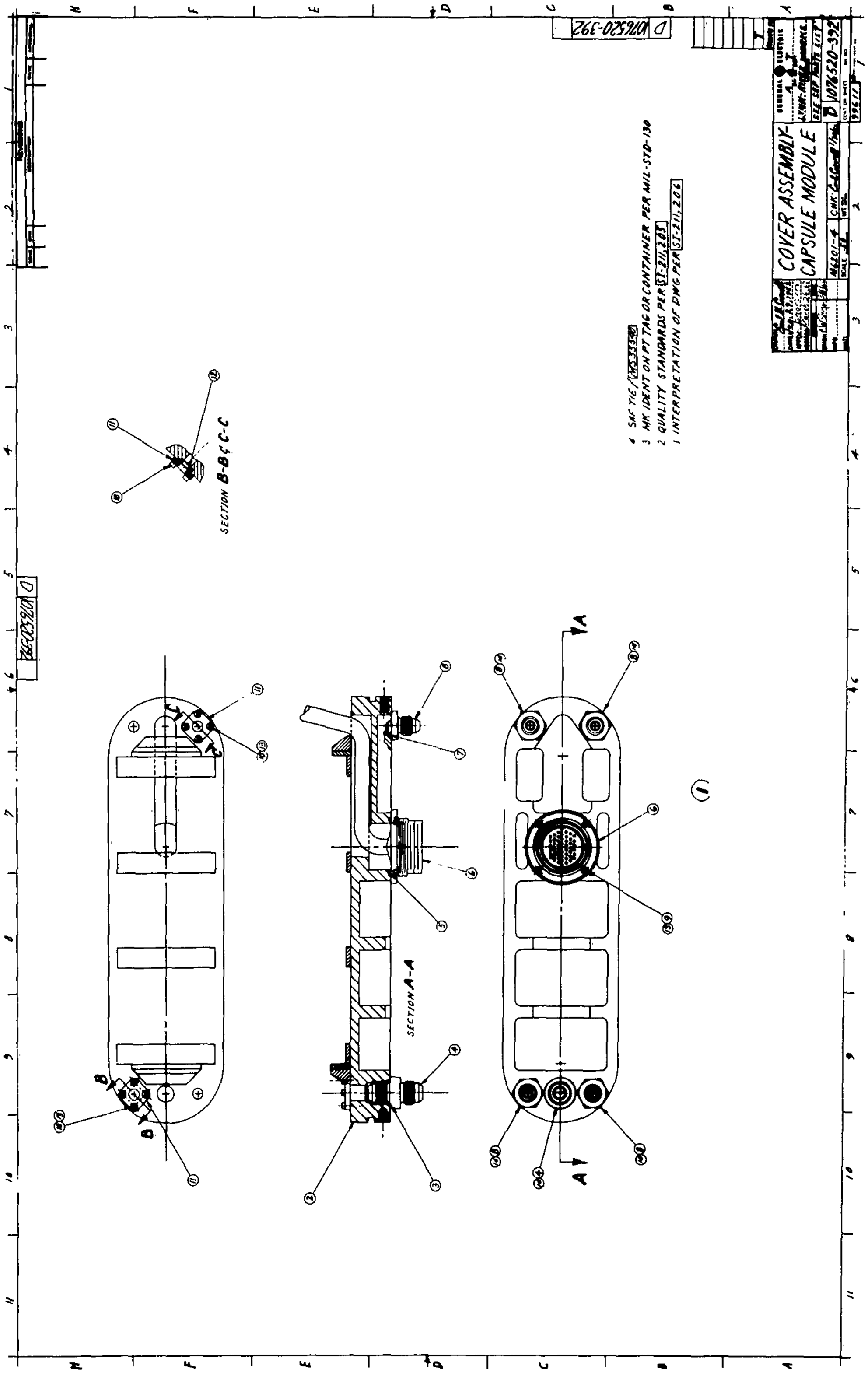
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON: FRACTIONS ± DECIMALS ± ANGLES ± ALL SURFACES ✓	DRAWN C. H. Carroll DATE Aug. 2, 1962 APPD ISSUED March 26, '62	MASK-HYDROGEN	GENERAL ELECTRIC A.A.T. DEPT LYNN-RIVER WORKS LOCATION
MATERIAL GOVT OR COML CARPENTER 20CB G.E.	ENGR MFG. MATL	M6105-4 CHK: SCALE 2/5 WT	SIZE C 1076520-350 CONT ON SHEET SH NO 99611

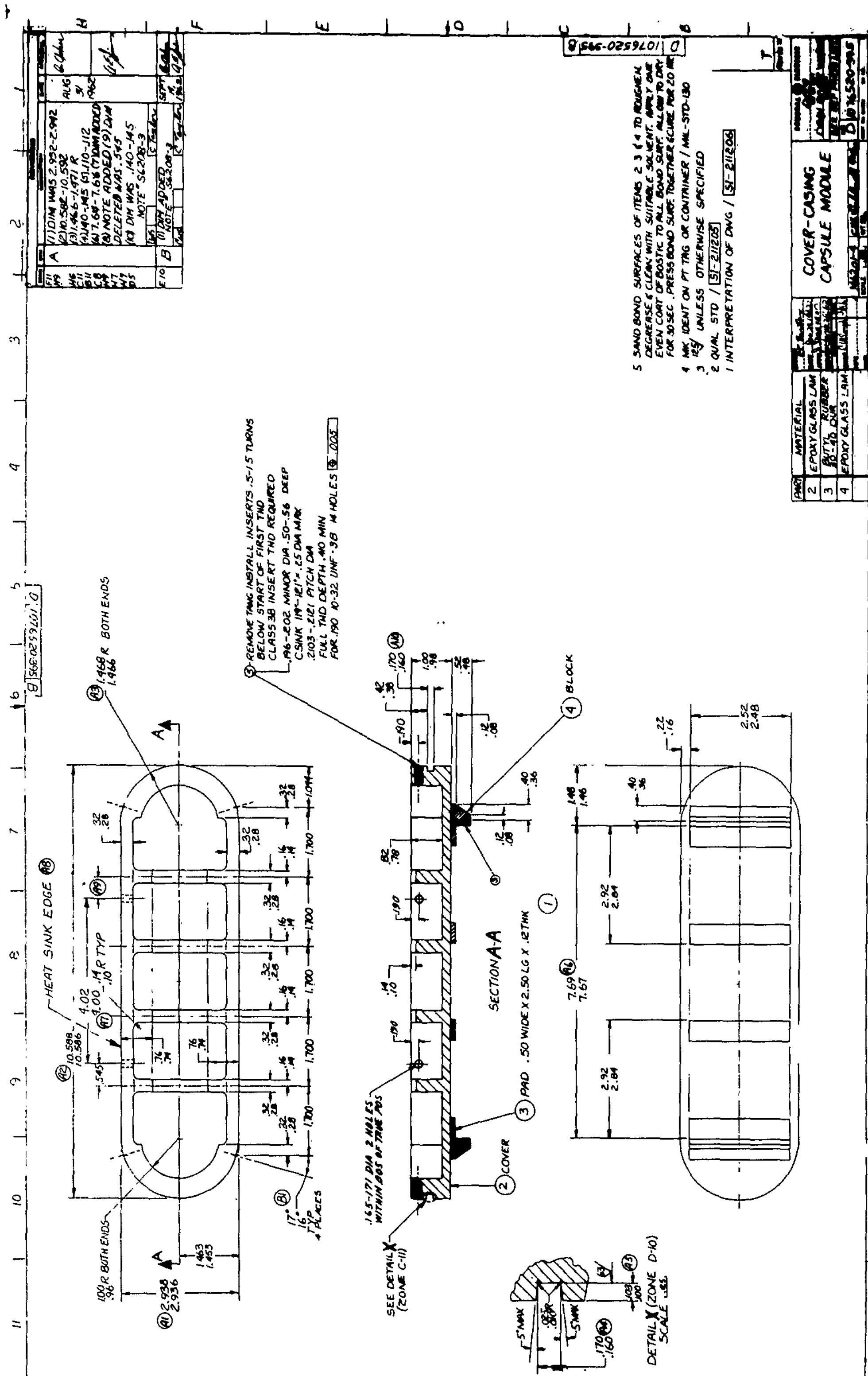

REVISIONS
SYM DESCRIPTION DATE APPROVAL
A (1) DIM WAS 1.86-1.90 (2) DIM ADDED (3) DIM WAS .20-.30 (4) .72-.76 NOTE #S6208-3
SEPT 5, 1962
B 1076520-390 A
3 MK IDENT ON PT TAG OR CONTAINER / MIL-STD-130
2 QUAL STD / 51-211205
1 INTERPRETATION OF DWG / 51-211206
1.83
1.79
A1
5.84
5.76
A2
6.04
5.96
.40
.30
A3
.50
.46
A4
30.30
30.20
.40
.36
1 STK THK .250
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON: FRACTIONS DECIMALS ANGLES
ALL SURFACES
MATERIAL
GOVT. OR COML. TROY IUF FELT TROY BLANKET MILLS TROY, N.H.
DRAWN
DATE
APPD
ISSUED
APPROVED DATE
ENGR.
MFG
MATL
TRANSPORT WICK
M6201-4
GENERAL ELECTRIC
DECO
LYNN RIVER WORKS
B 1076520-390
CODE IDENT NO. 14736

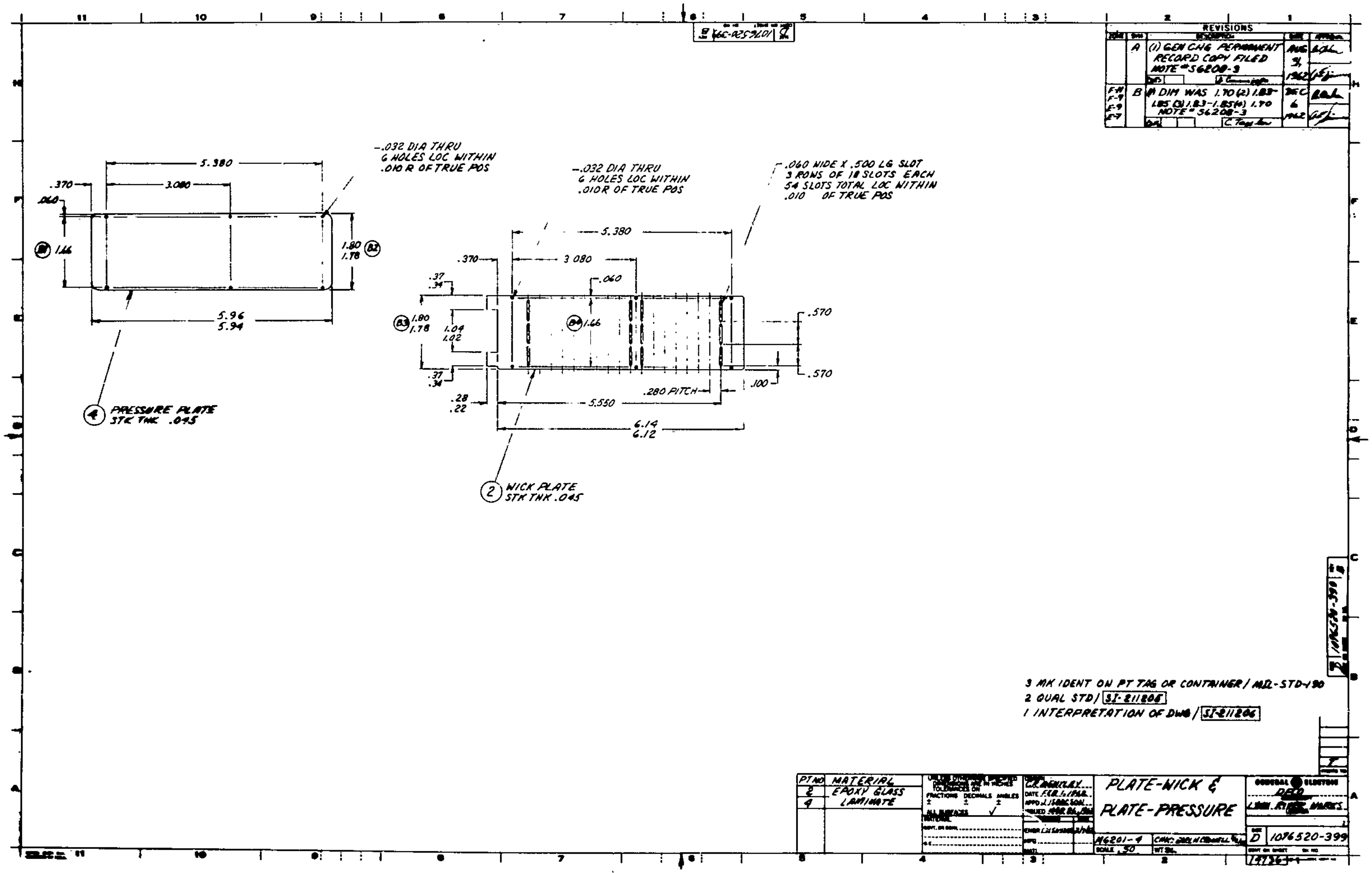

TAP DRILL DEPTH .38 MAX
C'SINK .10 DIA MAX
THD #2(.086)-56 UNC-3B
DEPTH .25 MIN
2 SETS OF 4 HOLES AS SHOWN
WITHIN .005 OF TRUE POS
SECTION B-B & CC (ZONE L-11 & L8)
SCALE .125
BLOCK (7)
(6) PAD .50 WIDE X 1.75 LG X.12 THK
(5) PAD .50 WIDE X 2.50 LG X.12 THK
(4) COVER
(ZONE D-13) SEE DETAIL X
REMOVE TANG INSTALL INSERT .5-1.5 TURNS BELOW START OF FIRST THD CLASS 3B INSERT THD REQD
.196-.202 MINOR DIA DEPTH .30-.36
C'SINK 119°-121° X .25 DIA MAX
.2103-.2121 PITCH DIA
FULL THD DEPTH .2 0 MIN
FOR .190 UNF-3B
1 HOLE WITHIN .005 OF TRUE POS
.375 DIA THRU
TAP DRILL DEPTH .60-.66
C'SINK 120° X .690-.705 DIA
TH'D .5625-18 UNF-3B
DEPTH .47 MIN
C'BORE .580-.585 DIA
DEPTH .083-.098
1 HOLE LOCATED AS SHOWN
SECTION A-A (ZONE C-7 TO C-11)
SEE DETAIL Y (ZONE K-5)
(1)
REMOVE TANG INS BELOW START OF F CLASS 3B INSERT
.196-.202 MINOR DI
C'SINK 119°-121° X .25
.2103-.2121 PITCH
FULL THD DEPTH
FOR #10(.190)-32 UNF
13 HOLES WITHIN .0
DETAIL X (ZONE H-11)
SCALE .125
HEAT SINK EDGE
17° TYP 16° 4 PLACES
1.468 R 1.466 BOTH ENDS
.260 DIA THRU
TAP DRILL DEPTH .60-.66
C'SINK 120° X .560-.575 DIA
TH'D .4375-20 UNF-3B
DEPTH .44 MIN
C'BORE .454-.459 DIA
DEPTH .075-.090
HOLES LOCATED AS SHOWN
TAP DRILL DEPTH .38
C'SINK .10 DIA MAX
THD #2(.086)-56 UNC-3B
DEPTH .22 MIN
4 HOLES WITHIN .005 OF TRUE POS
.0938 DIA 4 HOLES
C'BORE OPPOSITE SIDE
AS SHOWN IN SECTION F-F
(ZONE H-5)
10.588
10.586
PART SECTIONS D-D
1
14
13
12


REVISIONS
DETAIL Y (ZONE H-8)
SECTION A-A (ZONE C-7 TO C-11)
(5) PAD .50 WIDE X 2.50 LG X .12 THK
(4) COVER
SEE DETAIL Y (ZONE K-5)
(3) REMOVE TANG INSTALL INSERT .5-1.5 TURNS BELOW START OF FIRST THD CLASS 3B INSERT THD REQUIRED
.196-.202 MINOR DIA DEPTH .50-.56
C'SINK 119°-121° X .25 DIA MAX
.2103-.2121 PITCH DIA
FULL THD DEPTH .410 MIN
13 HOLES WITHIN .005 OF TRUE POS
PARTIAL SECT F-F (ZONE C-9)
HEAT SINK EDGE
.165-.171 DIA 2 HOLE WITHIN .005 OF TRUE POS
PART SECTIONS D-D & E-E
6 SAND BOND SURFACES OF ITEMS 4 & 7 TO ROUGHEN. DEGREASE & CLEAN WITH ACETONE. BOND ITEM 7 TO ITEM 4 USING ECCOBOND NO. 55 WITH NO. 9 CATALYST
5 SAND BOND SURFACES OF ITEMS 4, 5, & 6 TO ROUGHEN
DEGREASE AND CLEAN BOND SURFACES WITH SUITABLE SOLVENT
APPLY ONE EVEN COAT OF BOSTICK TO ALL BOND SURFACES
ALLOW TO DRY 30 SEC PRESS BOND SURF TOGETHER & CURE FOR 20 HRS
4 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130
3 UNLESS OTHERWISE SPECIFIED
2 QUALITY STANDARD PER SI-211,205
1 INTERPRETATION OF DWG PER SI-211,206
2
PART
MATERIAL
EPOXY GLASS LAM
COVER
CAPSULE MODULE

1K-19/1K-20


4 SAF TIE
3 MK IDENT ON PT TAG OR CONTAINER PER MIL-STD-130
2 QUALITY STANDARDS PER ST-211,205
1 INTERPRETATION OF DWG PER ST-211,206
COVER ASSEMBLY-
CAPSULE MODULE
D V076520-392
99611
SEE SEP PARTS LIST
GENERAL ELECTRIC
SECTION A-A
SECTION B-B & C-C
A
A
B
B
C
C


COVER-CASING
CAPSULE MODULE
SECTION A-A
HEAT SINK EDGE
BLOCK
COVER
PAD .50 WIDE X 2.50 LG X .12 THK
MATERIAL
EPOXY GLASS LAM



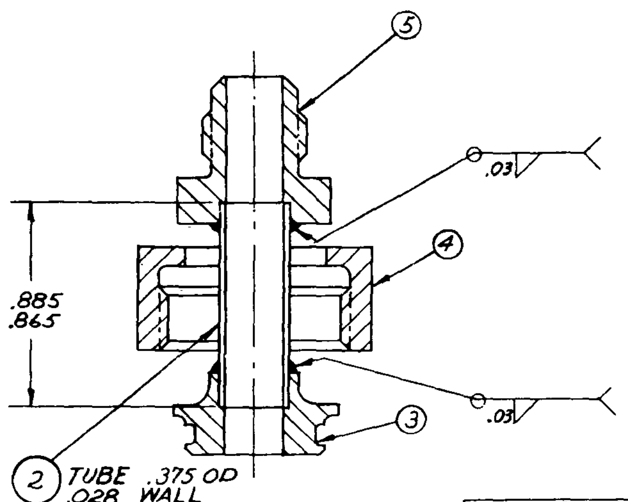
REVISIONS
A (1) GEN CHG PERMANENT RECORD COPY FILED NOTE # 56208-3
B DIM WAS 1.70 (2) 1.83-1.85 (3) 1.83-1.85(4) 1.70 NOTE # 56208-3
.032 DIA THRU
6 HOLES LOC WITHIN
.010 R OF TRUE POS
.032 DIA THRU
6 HOLES LOC WITHIN
.010 R OF TRUE POS
.060 WIDE X .500 LG SLOT
3 ROWS OF 18 SLOTS EACH
54 SLOTS TOTAL LOC WITHIN
.010 OF TRUE POS
5.380
3.080
.370
.060
1.66
1.80
1.78
5.96
5.94
4 PRESSURE PLATE
STK THK .045
5.380
3 080
.370
.060
.37
.34
1.80
1.78
1.04
1.02
1.66
.570
.570
.100
.280 PITCH
5.550
.28
.22
6.14
6.12
2 WICK PLATE
STK THK .045
3 MK IDENT ON PT TAG OR CONTAINER / MIL-STD-130
2 QUAL STD / SI-211806
1 INTERPRETATION OF DWG / SI-211806
PT NO | MATERIAL
2 | EPOXY GLASS
4 | LAMINATE
PLATE-WICK &
PLATE-PRESSURE
GENERAL ELECTRIC
D 1076520-399
M6201-4
SCALE 50

CONT ON SHEET FINAL SH NO. 1	SIZE B	1076524-94	REV

REVISIONS

SIZE B 1076524-94 REV
CONT ON SHEET FINAL SH NO. 1

SYM	DESCRIPTION	DATE	APPROVAL



4 WELD/ SI 211201
3 MK IDENT/ SI 211600
2 QUALITY STANDARDS/ SI 211,205
1 INTERPRETATION OF DRW / SI 211,206

T
PRINTS TO

1

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS ± DECIMALS ± ANGLES ±
ALL SURFACES ✓
MATERIAL
GOVT OR COML
G E

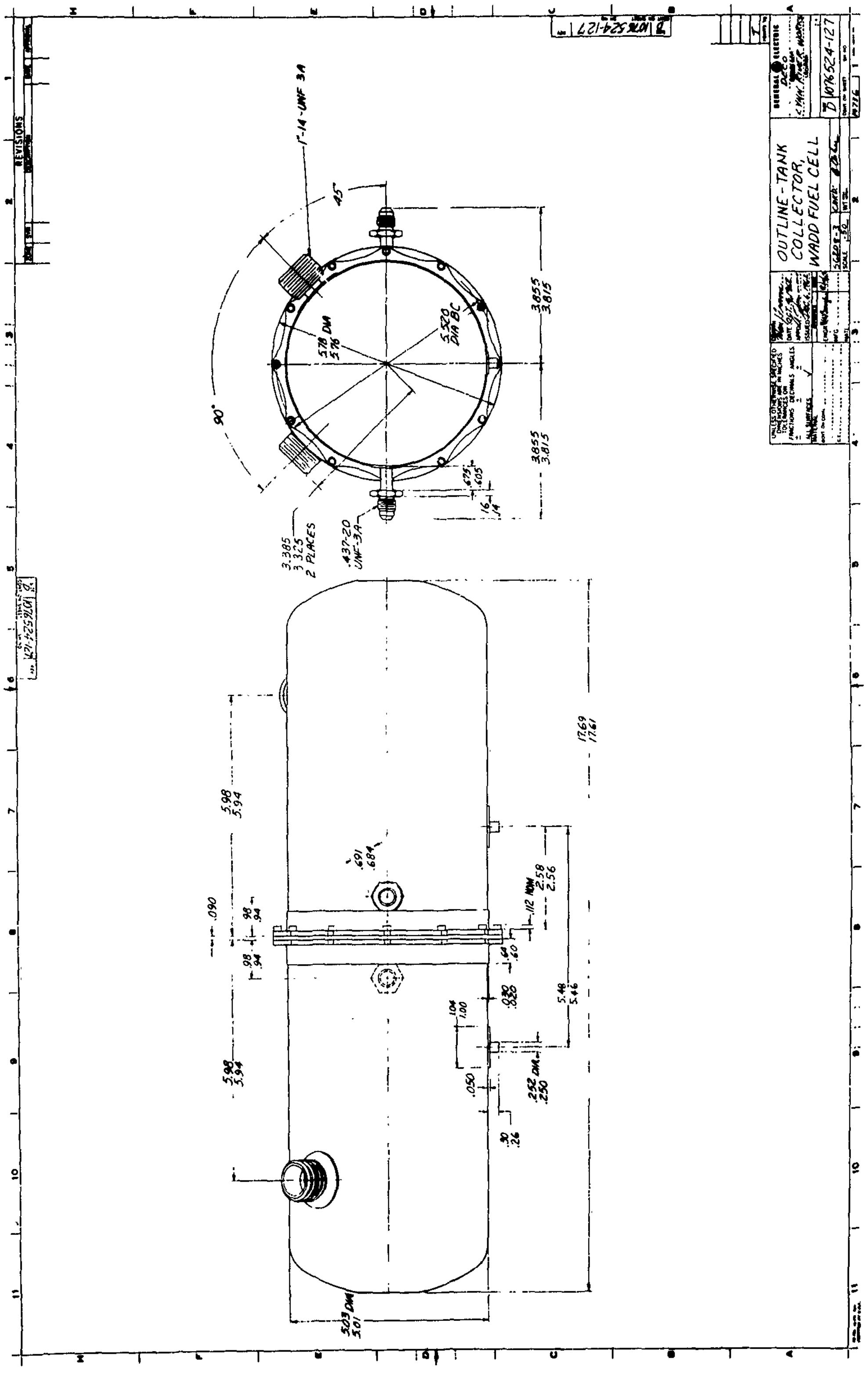
DRAWN C Taylor
DATE SEPT 21,1962
APPD
ISSUED SEPT 21,1962
APPROVED DATE
ENGR
MFG
MATL

WICK DISCONNECT ASSY

S6208-3
SCALE 2.5
CHK
WT CALC ACTUAL

GENERAL ELECTRIC
DECO
[redacted] DEPT
LYNN RIVER WORKS
LOCATION
SEE SEP PTS LIST
SIZE B 1076524-94
CONT ON SHEET — SH NO 1
CODE IDENT NO 14736

PRINTED IN U.S.A.


REVISIONS
OUTLINE - TANK
COLLECTOR,
WADD FUEL CELL
D 076524-127

APPENDIX 2A

DETAILED DESIGN CALCULATIONS

APPENDIX 2A

DETAILED DESIGN CALCULATIONS

A. PURGE SEQUENCER

The purge sequencer consists of 4-time delay switches in series, each of which is characterized by its own time delay and switching function. The basic time delay switch shown in Figure 2A-1 consists of a UJT time delay, and an SCR switch. The design equations covering the UJT time delay circuit are straightforward and presented in any basic transistor handbook.

The main design problem encountered was supplying sufficient energy to operate the latching relays with the contraints that

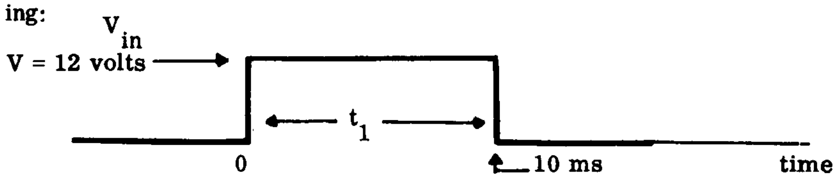
$R_5 C_2 < 1/5$ purge sequencer

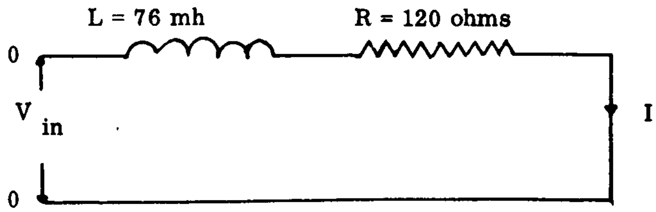
cycle and $R_5 < \frac{B+}{I_h}$

where I_h is the SCR holding current.

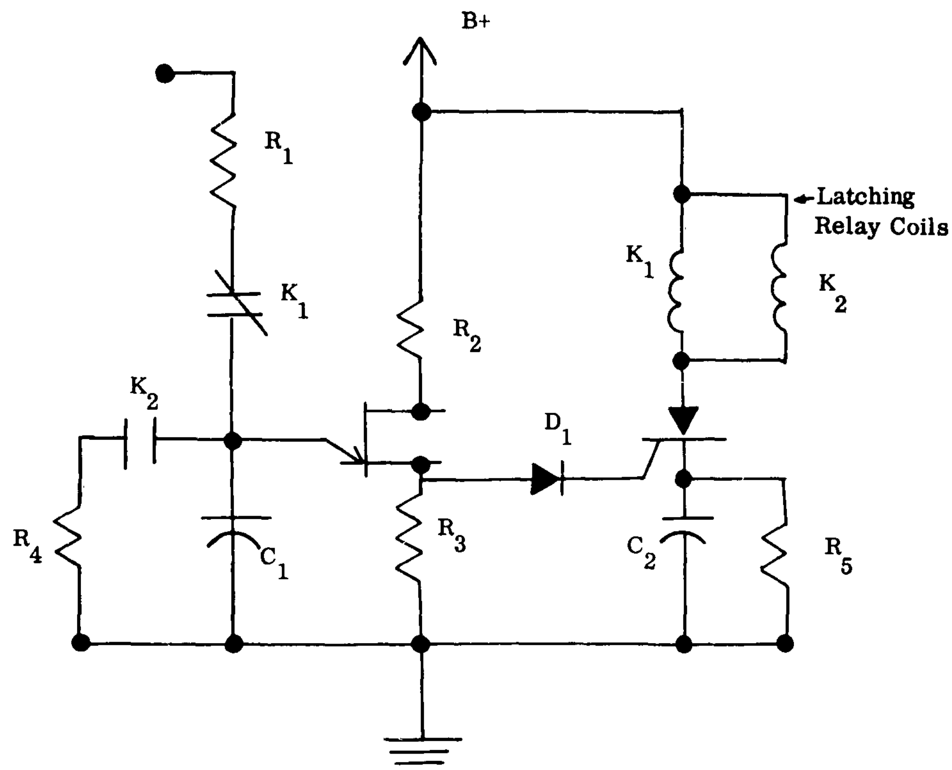
These constraints resulted in $R_5 = 50K\Omega$ and $C_2 < 56$ uf.

The minimum operating energy was specified by the manufacturer to be the amount of energy that resulted from the application of a square wave voltage, of specified amplitude and width, across the relay coil. Therefore, the first step in the design was to solve for this minimum operating energy. Using the specific specifications and relay parameters, the problem reduced to the following:





Energy supplied to the circuit.



PURGE SEQUENCER BASIC TIME DELAY SWITCH

Figure 2A-1

Writing the Laplace transform loop equation gives:

$$V(S) = (SL + R)\, I(S)$$

where

$$V(S) = \left[\frac{V}{S} - \frac{V}{S} e - t_1 S\right]$$

Solving for I (S) gives:

$$I(S) = \frac{V(1 - \exp [- tis])}{S(SL + R)}$$

using the inverse Laplace transform gives:

$$I(t) = \frac{V}{R}\left[1 - \exp\left(\frac{-Rt}{L}\right)\right.$$

$$\left. - \mu(t - t_1) + \exp \quad -\frac{R}{L}\, \mu(t - t_1)\right]$$

where $\mu(t - t_1)$ is defined as

$$\mu(t - t_1) = 1 \quad t > t_1$$

$$= 0 \quad t < t_1$$

Electrical Energy, E , is defined as

$$\int_0^{t} V(t)\, I(t)\, dt$$

in this case

$$V(t) = V \quad 0 < t < t_1$$

$$= 0 \quad t < 0$$

$$t > t_1$$

$$I(t) = \frac{V}{R}\left[1 - \exp\frac{-R\,t}{L}\right]$$

$$\text{for } 0 < t < t_1$$

$\therefore$ the energy equation becomes

$$E = \int_0^{t_1} V\,\frac{V}{R}\left\{1 - \exp\left(\frac{-R\,t}{L}\right)\right\} dt$$

which upon integrating yields

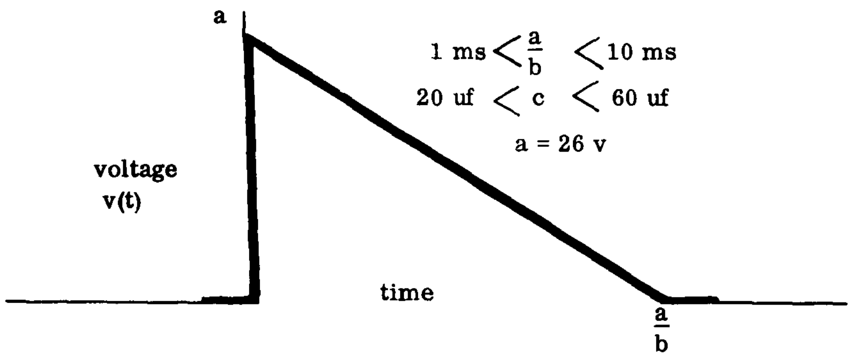
$$E = \frac{V^2}{R}\left[t + \frac{L}{R}\exp\frac{-Rt}{L}\right]_0^{t_1}$$

substituting the proper values of R_1, L_1, V and t_1 yields:

$$E = 11.2 \times 10^{-3} \text{ Joules}$$

which is the minimum energy required to operate the relay.

By using the values of $R_5 = 50\ K\ \Omega$ and $C_2 = 20$ uf to 60 uf in the actual switching circuit it was found that the relay voltage waveshape could be closely approximated by the following waveshape:



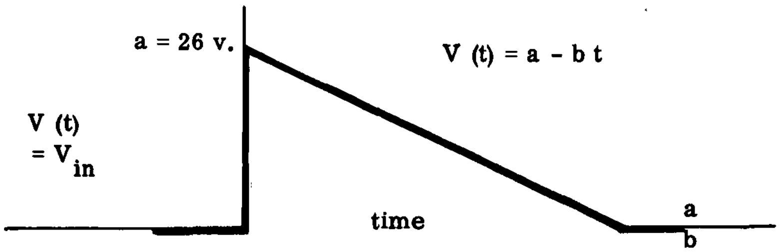
$$\text{where } V(t) = a - bt \qquad 0 < t < \frac{a}{b}$$

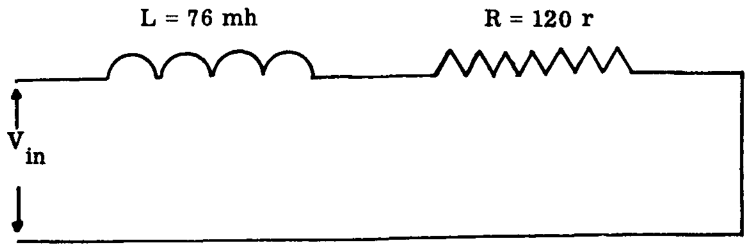
$$= 0 \qquad t < 0$$

$$\qquad t > \frac{a}{b}$$

the next step was to find the time a/b which resulted in the application of twice the minimum energy to the relay. Once this could be found, the value of C2 corresponding to this time could be found.

Therefore, the next step was to solve the following problem:





solve for the energy supplied to the circuit

using Laplace transforms again

$$V(S) = (SL + R)\, I(S)$$

$$V(S) = \frac{a}{b} - \frac{b}{S^2}$$

$$I(S) = \left(\frac{a}{s} - \frac{b}{s^2}\right)\left(\frac{1}{SL} + R\right)$$

using the inverse Laplace transform gives

$$I(t) = \left(\frac{a}{R} + \frac{bL}{R^2}\right)\left(1 - \exp\left[\frac{-R}{L}\,t\right]\right) - \frac{bt}{R}$$

for $0 < t < \frac{a}{b}$

solving for the energy E gives

$$E = \int_0^{t_1} \left(\frac{ab}{R} + \frac{b^2L}{R^2}\right) \left(t \exp\left[\frac{-R}{L} t\right]\right) dt$$

$$-\int_0^{t_1} \left(\frac{a}{R} + \frac{abL}{R^2}\right) \left(\exp\left[\frac{-R}{L} t\right]\right) dt$$

$$-\int_0^{t_1} \left(2\frac{a}{R} b + \frac{b^2L_2}{R}\right) t \ dt$$

$$+\int_0^{t_1} \left(\frac{b^2t^2}{R}\right) dt + \int_0^{t_1} \left(\frac{a^2}{R} + \frac{abL}{R^2}\right) dt$$

upon integrating and letting $t_1 = \frac{a}{b}$

$$E = \frac{b^2L^2}{R^4} + \frac{a^3}{3Rb} - \frac{a^2L}{2R^2}$$

$$\left(-\frac{abL^2}{R^3} - \frac{b^2L^3}{R+}\right) \left(\exp\left[-\frac{R}{L}\frac{a}{b}\right]\right)$$

Letting $E = 2\ (11.2 \times 10^{-3})$ Joules and solving for b graphically gives

$$\frac{a}{b} = 10 \text{ ms}$$

which corresponded to a value of +47 uf for C_2.

The parameters of the switching circuit were now arranged so that twice the minimum operating energy was supplied to the relay switches.

B. VOLTAGE SENSOR CALIBRATING POTENTIOMETER

The equivalent circuit of the input stage of the voltage sensor is shown in Figure 2A-2. The problem was to determine whether a single turn potentiometer was adequate for calibrating the sensors.

The voltage V_2 at the emitter of the sensing transistor is given by

$$V_2 = \frac{V_1 R_{equivalent}}{R + R_{equivalent}}$$

where $R_{equivalent} = \dfrac{1K\ (5K-R)}{5K - R + 1K}$

$$\therefore \quad V2 = \frac{\dfrac{V1\ 1K\ (5K - R)}{6K - R}}{R + \dfrac{1K\ (5K - R)}{6K - R}}$$

clearing fractions and simplifying gives

$$V_2 = \frac{V_1\ (5K - R)\ 1K}{(5R + 5K)\ 1K - R^2}$$

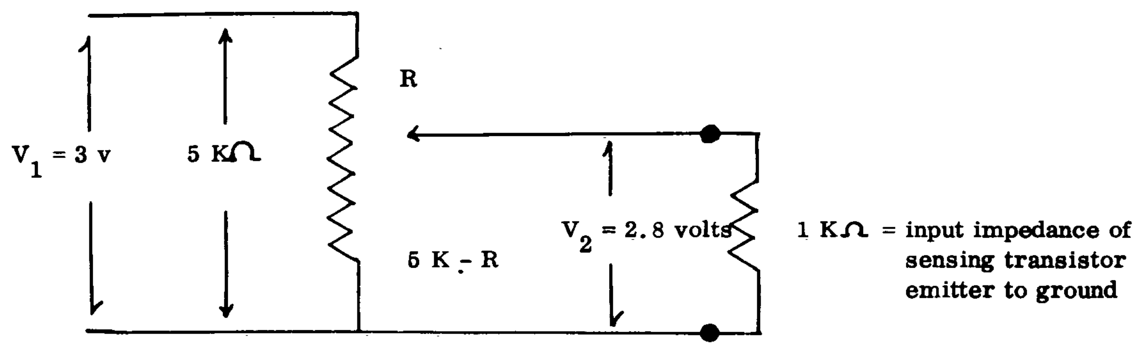
for $V_2 = 2.8$ volts
$R < 75\Omega$

$\therefore$ neglecting the R^2 term in the numerator gives

$$V_2 = \frac{(5K - R)\ V_1}{5K + 5\ R}$$

It was desirable to set $V_2 = 2.8$ volts $\pm .05$ volts

for $V_2 = 2.85$ volts
$R = 41\Omega$
and



EQUIVALENT CIRCUIT OF THE INPUT STAGE OF THE VOLTAGE SENSOR

Figure 2A-2

for $V_2 = 2.75$ volts

$R = 74\Omega$

assuming a single turn pot with a linear function

$$\frac{\Delta R}{\Delta \Theta} = \frac{5\ K}{360^{o}}$$

and using $\Delta R = 74\Omega - 41\Omega = 33\Omega$

the range of wiper travel

$\Delta\Theta 1$ required to set $V_2 = 2.8 \pm .05$ volts was found to be

$$\Delta\Theta 1 = \frac{360}{5\ K}\ 33 = .24^{o}$$

which was considered too critical a setting to be achieved easily.

A commercially available 10 turn potentiometer with a $\frac{\Delta R}{\Delta\Theta}$ function equal to $\frac{14\Omega}{\text{degree}}$ was investigated next.

The range of wiper travel $\Delta\Theta 2 = \frac{1\ \text{deg.}}{14\Omega}\ 33\Omega = 2.4^{o}$

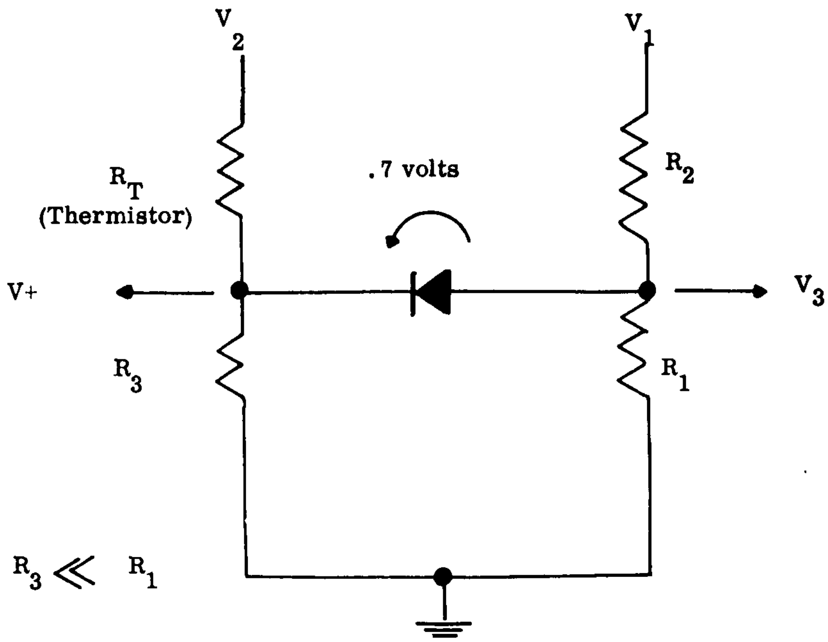
which was considered an adequate range for ease of adjustment.

C. TEMPERATURE SENSOR

The problem was to specify the thermistor and gate resistors to be used in the majority logic temperature sensor. The equivalent circuit of one of the $140^{o}F$ gates is shown in Figure 2A-3.

The constraints are

$$V_2 = V_1 = 20 \text{ volts}$$



EQUIVALENT CIRCUIT OF ONE MAJORITY
LOGIC GATE

Figure 2A-3

$V_3 = 14$ volts

$_{max}$ and $R_3 \ll R1$

assume $R_1 = 1$ meg Ω and the coupling diode disconnected

$\therefore V_3 = \frac{V_1}{R_1+R_2} R_2$

substituting the values

$V_1 = 20$ volts

$V_3 = 12$ volts

$R_1 = 1$ MegΩ

and solving for R_2 gives

$R_2 = 430$ K

The level of V_3 needed to perform the required switching function, with the coupling diode connected, is 12 volts

$V_4 = V_3 - .7$

$V_4 = 11.3$ volts

Since $V_2 = 20$ volts and $V_4 = 11.3$ volts and $R_3 \ll R_1$ a thermistor was chosen such that its value of resistance at the temperature of interest was $\ll R_1$ since

$$V_4 = \frac{V_2}{RT + R_3} R_3$$

solving for R_3 gives

$$\frac{V + RT}{V_2 - V_4} = R_3$$

substituting the values of V_2 and V_4 and the value of RT at 140°F gives

$R_3 = 30$ KΩ

For the 125° F gates the position of R_3 and RT are interchanged, while $R_1 + R_2$ remain the same. For this condition

$$V_4 = \frac{V_2 \; RT}{RT + R_3}$$

solving for R_3 gives

$$R_3 = \frac{(V_2 - V_4) \; RT}{V_4}$$

substituting the values of V_2 and V_4 and the value of RT at 125°F gives

$$R_3 = 24 \; K\Omega$$

APPENDIX 2B

DETAILED RELIABILITY ANALYSES AND SUMMARY TABLES FOR FUEL CELL CONTROL ELECTRONICS

APPENDIX 2B

DETAILED RELIABILITY ANALYSES AND SUMMARY TABLES FOR FUEL CELL CONTROL ELECTRONICS

Appendix 2B contains the detailed reliability analysis information which includes parts usage and application data for the FCC and FSSC, a FCC summary table listing the FCC functional circuits, and a detailed analysis for the FSSC. Explanatory comments are included where necessary indicating the assumptions of the specific circuit involved. The reliability analysis was carried out for a FCC and a FSSC for one fuel cell module only.

This permits a system analysis to be computed when a system configuration, which would include the Phase 2 Power Control Source Selector Unit, is finalized. A system analysis cannot be completed since the PCSSU would have provided sequential switching of the power sources available for the telemetry load.

FUEL CELL CONTROL RELIABILITY ESTIMATE SUMMARY TABLE

Functional Circuit	Failures/Mission
Purge Voltage Sensors and Series Regulator	.00437
Timers and Counters	.00198
Purge Sequencers	.00070
Temperature Sensors	.00168
Ascent Pulser	.00002
	.00875

$R_{FCC} = \epsilon^{-.00875}$

$R_{FCC} = .9913$ (For one Fuel Cell Controller)

FUEL CELL CONTROLLER

Purge Voltage Sensors and Series Regulator

Parts	N	$\Sigma\lambda$ (%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	28	.0465	
Diodes	18	.0198	
Resistors	30	.0274	
Potentiometers	14	2.0300	
Relays	13		749.7
Solder Joints	300	.0300	
TOTALS		2.1537	749.7

For t = 7 days = 168 hours:

$$\Sigma\lambda t_{(\text{time dependent})} + \Sigma\lambda_{(\text{cyclic})} = (2.1537\text{x}10^{-5})(168)+(749.7\text{x}10^{-6})$$

$$\Sigma\lambda t_{(\text{time dependent})} + \Sigma\lambda_{(\text{cyclic})} = .00362 + .00075$$

$$\Sigma\lambda t_{(\text{time dependent})} + \Sigma\lambda_{(\text{cyclic})} = .00437$$

TIMERS AND COUNTERS

Parts	N	$\Sigma\lambda$(%/1000 hours)
Transistors	16	.0256
Resistors	57	.6783
Capacitors	16	.1066
Diodes	17	.0212
Transformers	8	.3200
Solder Joints	276	.0276
		1.1793

For t = 7 days = 168 hours

$\Sigma\lambda t = (1.1793\text{x}10^{-5})(168) = .00198$

PURGE SEQUENCERS (HYDROGEN AND OXYGEN)

Parts	N	$\Sigma\lambda$(%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	6	.0144	
SCR's	6	.0096	
Diodes	14	.0154	
Resistors	31	.0481	
Capacitors	16	.3900	
Relays	6		617.4
Solder Joints	194	.0194	
TOTALS		.4969	617.4

The purge sequencer circuitry will be essentially under storage conditions for all but 168 minutes (maximum) of the seven day mission. In an effort to approximate the storage condition failure rates, a factor of 0.1 will be applied to the time dependent failure rate summation.

For t = 7 days = 168 hours:

$$\Sigma\lambda t \text{ x } 10^{-1}{}_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = (.4969\text{x}10^{-6})(168)+(617.4\text{x}10^{-6})$$

$$\Sigma\lambda t \text{ x } 10^{-1}{}_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = .000083 + .000617$$

$$\Sigma\lambda t \text{ x } 10^{-1}{}_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = .0007$$

MAJORITY LOGIC TEMPERATURE SENSORS (125°F AND 140°F)

Parts	N	$\Sigma\lambda$ (%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	2	.0040	
SCR's	2	.0032	
Diodes	20	.0220	
Resistors	14	.0130	
Relays	1		.350
Capacitors	4	.0780	
Potentiometers	6	.8700	
Solder Joints	112	.0112	
TOTALS		1.0014	.350

For t = 7 days = 168 hours

$$\Sigma\lambda t_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = (1.0014\text{x}10^{-5})(168) + (.35\text{x}10^{-6})$$

$$\Sigma\lambda t_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = .00168 + .00000035$$

$$\Sigma\lambda t_{\text{(time dependent)}} + \Sigma\lambda_{\text{(cyclic)}} = .00168 \quad (R \cong .9984)$$

The function of the temperature sensors is to disconnect and reconnect the load from and to the fuel cell if the cell becomes overheated by solar energy incident on the radiator. It is assumed that overheating will occur only if the attitude of the vehicle is such that the radiators face the sun for prolonged periods of time. The probability of this occurrence is estimated to be very small, and it has not been considered in this analysis. Therefore, the above failure rate-time product (.00168) is very pessimistic.

ASCENT PULSER CIRCUITRY
(Functional During Ascent Only)
(Space Factors, K_s, Not Applied to Failure Rates)

Parts	N	$\Sigma\lambda$ (%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	1	.0056	
SCR's	2	.0064	
Diodes	3	.0066	
Resistors	6	.0108	
Capacitors	3	.0850	
Relays	1		24.5
Solder Joints	39	.0039	
TOTAL		.1183	24.5

For t = 15 minutes = .25 hours

$$\Sigma\lambda t_{(\text{time dependent})} + \Sigma\lambda_{(\text{cyclic})} = (.1183\text{x}10^{-5}(.25) + (24.5\text{x}10^{-6})$$

$$\Sigma\lambda t_{(\text{time dependent})} + \Sigma\lambda_{(\text{cyclic})} = .00002$$

FUEL SUPPLY SHUTOFF CONTROLLER RELIABILITY ESTIMATE
Summary Table

Parts	N	$\Sigma\lambda$(%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	13	.0208	
Diodes	11	.0121	
Resistors	22	.0176	
Potentiometers	11	1.5950	
Relays	4		.3500
Solder Joints	162	.0162	
		1.6617	.3500

(From FCC Schematic)

Parts	N	$\Sigma\lambda$(%/1000 hrs)	$\Sigma\lambda(10^{-6}$/mission)
Transistors	1	.0028	
SCR's	2	.0032	
Diodes	4	.0044	
Resistors	6	.0059	
Capacitors	3	.0850	
Relays	1		24.5
Solder Joints	41	.0041	
		.1054	24.5
TOTAL		1.7671	24.85

For t = 7 days = 168 hours

$$R_{FSSC} = \epsilon^{-\left[(1.7671\text{x}10^{-5})(168) + (24.85\text{x}10^{-6})\right]}$$

$R_{FSSC} = \epsilon^{-.0030} = .9970$ (For one fuel cell module only. Fuel Supply Shutoff Controller contains circuitry for two fuel cell modules.)

FORM 4-13 PART USAGE AND APPLICATION DATA

TIMER/COUNTER

TRANSISTORS, ALL CLASSES

COMPONENT DESIGNATION FCC   ASSEMBLY DRAWING ______   WIRING DIAGRAM ______   SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	POWER RATING - MAX* VALUE	%Du Cy	@T_A or T_C (°C)	USAGE - MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES	%Du Cy	CURRENTS VALUES	%Du Cy	VOLTAGES VALUES	%Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
GT Dwg. No. 206-1207B														
			mw	%	°C		mw	%						
Q2	2N717	Rheem or TI	400	100	25		70	10^{-4}						.0016
Q3	2N717	" " "	400	100	25		40	100						.0016
GT Dwg. No. 206-1205A														
Q1	2N717	Rheem or TI	400	100	25		70	10^{-4}						.0016
Q2	2N717	" " "	400	100	25		70	$5x10^{-5}$						.0016
Q3	2N717	" " "	400	100	25		70	$5x10^{-5}$						.0016
Q4	2N717	" " "	400	100	25		70	$5x10^{-6}$						.0016
Q5	2N717	" " "	400	100	25		70	$5x10^{-6}$						.0016
Q6	2N717	" " "	400	100	25		70	$5x10^{-7}$						.0016
GT Dwg. No. 206-1209B & No. 206-1217B														
Q1	2N717	Rheem or TI	400	100	25		70	10^{-6}						.0016
Q2	2N717	" " "	400	100	25		70	10^{-6}						.0016
Q3	2N717	" " "	400	100	25		70	10^{-6}						.0016
GT Dwg. No. 206-1208B														
Q1	2N717	Rheem or TI	400	100	25		70	$<10^{-6}$						.0016
Q2	2N717	" " "	400	100	25		70	$<10^{-6}$						.0016
Q3	2N717	" " "	400	100	25		70	$<10^{-6}$						.0016
Q4	2N717	" " "	400	100	25		70	$<10^{-6}$						.0016

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753N (8-61)

TIMER/COUNTER

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, Mil or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER WATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
GT Dwg. No. 206-1207B				%	Watt	mw	%			
R1	CB	A-B	Approx 430K	±10	1/4	.25	0.1			.0119
R2	"	"	10K	"	"	.005	0.002			
R3	"	"	220	"	"	5.5	2.2			
R4	"	"	47K	"	"	$2.5x10^{-3}$	0.001			
R5	"	"	27	"	"	.8	0.32			
R6	"	"	150	"	"	10^{-4}	$4x10^{-5}$			
R7	"	"	27	"	"	$1.25x10^{-4}$	$5x10^{-5}$			
R8	"	"	220	"	"	10^{-3}	$4x10^{-4}$			
R10	"	"	180	"	"	5	2			
R11	"	"	4.7K	"	"	1.7	0.7			
GT Dwg. No. 206-1205A										
R1	CB	A-B	270	±10	1/4	$6x10^{-5}$	$2.4x10^{-5}$			
R2	"	"	1K	"	"	10^{-6}	$4x10^{-7}$			
R3	"	"	180	"	"	$<10^{-3}$	$<10^{-3}$			
R4	"	"	220	"	"	During reset only				
R5	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R6	"	"	27	"	"	$<10^{-3}$	$<10^{-3}$			
R7	"	"	220	"	"	$<10^{-3}$	$<10^{-3}$			
R8	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R9	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R10	"	"	27	"	"	$<10^{-3}$	$<10^{-3}$			
R11	"	"	220	"	"	$<10^{-3}$	$<10^{-3}$			
R12	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			

FORM 1-9783J (8-61)

TIMER/COUNTER

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER WATTS mw	% OPERATING TO RATED POWER %	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R13	CB	A-B	82	±10	1/4	$<10^{-3}$	$<10^{-3}$			.0119
R14	"	"	27	"	"	$<10^{-3}$	$<10^{-3}$			
R15	"	"	220	"	"	$<10^{-3}$	$<10^{-3}$			
GT Dwg. No. 206-1209B & No. 206-1217B										
R1	CB	A-B	270	±10	1/4	10^{-2}	$4x10^{-3}$			
R2	"	"	1K	"	"	$<10^{-3}$	$<10^{-3}$			
R3	"	"	100K	"	"	$<10^{-3}$	$<10^{-3}$			
R4	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R5	"	"	680	"	"	$<10^{-3}$	$<10^{-3}$			
R6	"	"	56	"	"	$<10^{-3}$	$<10^{-3}$			
R7	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R8	"	"	220	"	"	During	reset only			
R9	"	"	82	"	"	$<10^{-3}$	$<10^{-3}$			
R10	"	"	27	"	"	$<10^{-3}$	$<10^{-3}$			
R11	"	"	220	"	"	$<10^{-3}$	$<10^{-3}$			
GT Dwg. No. 206-1208B										
R1	CB	A-B	270	±10	1/4	$<10^{-3}$	$<10^{-3}$			
R2	"	"	1K	"	"	< "	< "			
R3	"	"	180	"	"	< "	< "			
R4	"	"	220	"	"	< "	< "			
R5	"	"	15	"	"	< "	< "			
R6	"	"	82	"	"	< "	< "			
R7	"	"	220	"	"	< "	< "			
R8	"	"	82	"	"	< "	< "			
R9	"	"	82	"	"	< "	< "			

FORM 1-9753J (8-61)

TIMER/COUNTER

COMPONENT DESIGNATION FCC

RESISTORS

CXT SYMS NO.	TYPE NO.	MFR.	RES. VALUE OHMS	%	watts	mw	%		Failure Rate %/1000 Hours
R10	CB	A-B	27	±10	1/4	< 10-3	< 10-3		.0119
R11	"	"	220	"	"	< "	< "		
R12	"	"	270	"	"	< "	< "		
R13	"	"	1K	"	"	< "	< "		
R14	"	"	33K	"	"	< "	< "		
GT Dwg. No. 206-1206A									
R1	CB	A-B	33K	±10	1/4	< 10-3	< 10-3		
R2	"	"	270	"	"	< "	< "		
R3	"	"	1K	"	"	< "	< "		
R4	"	"	27	"	"	7.5	10-5		
R5	"	"	1K	"	"	< 10-3	< 10-3		
R6	"	"	270	"	"	7.5	10-5		
R7	"	"	1K	"	"	< 10-3	< 10-3		

PART USAGE AND APPLICATION DATA

TIMER/COUNTER

CAPACITORS

COMPONENT DESIGNATION FCC — ASSEMBLY DRAWING — WIRING DIAGRAM — SCHEMATIC DIAGRAM

CKT. SYMB. NO.	TYPE NO. (GE, MIL OR VENDOR)	MFR.	CAP. VALUE MFD.	TOL. %	RATED VOLTAGE	OPERATING VOLTAGE	% OPERATED TO RATED VOLTAGE	OPERATING AMBIENT TEMP. °C	CIRCUIT FUNCTION OR APPLICATION	FAILURE RATE % 1000 HOURS
GT Dwg. No. 206-1207B							%			
C1	109D106X0050C2	Sprague	10Mfd	±20	50 VDC	6 VDC	12			.0100
C2	601 PE	Goodall	.047 mfd	±10	" "	12 "	24			.0005
C3	150D335X0015A2	Sprague	3.3 mfd	±20	15 "	12 "	80			.0150
GT	Dwg 206-1205A									
C1	150D335X0015A2	Sprague	3.3 mfd	±20	15 VDC	12 VDC	80			.0150
GT Dwg. No. 206-1209B & No. 206-1217B										
C1	M2W-F	Standard	0.1 MF	±10	200 VDC	12 VDC	6			.0015
C2	150D335X0015A2	Sprague	3.3 MF	±20	15 "	12 "	80			.0150
GT Dwg. No. 206-1208B										
C1	MIN-M-.002-M	Glenco	.002 MF	±20	75 "	20 "	27			.0015
C2	VK30CW103	Vitranon	.01 MF	±20	200 "	20 "	10			.0015
C3	150D335X0015A2	Sprague	3.3 MF	±20	15 "	12 "	80			.0150
GT Dwg. No. 206-1206A			MF		V DC	V DC				
C1	MIN-M-.002-M	Glenco	.002	±20	75	20	27			.0015
C2	Vk30C W103	Vitramon	.01	±20	200	20	10			.0015
C3	109D187X0025T2	Sprague	180	±20	25	20	80			.0100
C4	MIN-M-.002-M	Glenco	.002	±20	75	20	27			.0015
C5	VK30C W103	Vitramon	.01	±20	200	20	10			.0015
C6	150D685X0035	Sprague	6.8	±20	35	20	57			.0078
C7	150D685X0035	Sprague	6.8	±20	35	20	57			.0078

FORM 1-9753A REV. (11-61)

$\Sigma\lambda$ = .1066

TIMER/COUNTER **PART 4-4 PART USAGE AND APPLICATION DATA**
DIODES, SEMICONDUCTOR, ALL CLASSES

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ____ WIRING DIAGRAM ____ SCHEMATIC DIAGRAM ____

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE	% Du Cy %	@T_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES	% Du Cy	CURRENTS VALUES	% Du Cy	VOLTAGES VALUES	% Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
CR4	1N658	G.I.	200 ma	100	25°C		160 ma	$2x10^{-3}$						.0011
SCR1	3D1036	SSPI	200 ma	100	75°C		160 ma	$2x10^{-3}$						0016
GT Dwg. No. 206-1206A														
CR1	1N658	G.I.	200 ma	100	25°C		18ma	$2x10^{-7}$						.0011
CR2	1N658	G.I.	200 ma	100	25°C		80ma	$2x10^{-3}$						.0011
CR3	1N462A	C.D.C.	200 ma	100	25°C		100 ma	$2x10^{-7}$						.0011
CR4	1N752	T.I.	400 mw	100	50°C		300 mw	10^{-5}						.0011
CR5	1N658	G.I.	200 ma	100	25°C		18ma	$2x10^{-7}$						.0011
SCR1	3D1036	SSPI	200 ma	100	75°C		80ma	$2x10^{-3}$						.0016
SCR2	3D1036	SSPI	10 amps	0.3	25°C		1.5 amps	10^{-5}						.0016

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753D (8-61)

PART 4-4 PART USAGE AND APPLICATION DATA
DIODES, SEMICONDUCTOR, ALL CLASSES

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE	% Du Cy	T_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES	% Du Cy	CURRENTS VALUES	% Du Cy	VOLTAGES VALUES	% Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
GT Dwg. No. 206-1207B														
CR1	SV135	Transitron	250 mw	100	25°C		21 mw	100						.0011
SCR1	3D1036	SSPI	200 ma	100	75°C		50 ma	10^{-4}						.0016
Q1	2N1671B	G.E.	450 mw	100	25°C		40 mw	100					(TRANSISTOR)	.0016
GT Dwg. No. 206-1205A														
CR1	1N658	G.I.	200 ma	100	25°C		80 ma	During reset only.						.0011
GT Dwg. Nos. 206-1209B & 206-1217B														
CR1	1N658	G.I.	200 ma	100	25°C		80 ma	During reset only.						.0011
SCR1	3D1036	SSPI	200 ma	100	75°C		50 ma	10^{-4}						.0016
GT Dwg. No. 206-1208B														
CR1	1N658	G.I.	200 ma	100	25°C		80 ma	During reset only.						.0011
CR2	1N658	G.I.	200 ma	100	25°C		18 ma	$2x10^{-7}$						.0011
CR3	1N462	C.D.C.	200 ma	100	25°C		100ma	$2x10^{-7}$						.0011

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753D (8-61)

$\Sigma\lambda = .0212$

TIMER/COUNTER

FORM 4-5 PART USAGE AND APPLICATION DATA

TRANSFORMERS

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	INSULATION OR TEMP. CLASS	TYPE CONSTRUCTION (SEALED, ENCAP.,)	OPERATING AMBIENT TEMP. °C	HOT SPOT TEMP °C	INDUCTANCE	APPLICATION INFO.	FAILURE RATE %/1000 HOURS
GT Dwg. No. 206-1207B									
T1	A28128	Proprietory	HAT	Sealed					.04
GT Dwg. No. 206-1205A									
T1	A28128	Proprietory	"	"					.04
T2	"	"	"	"					.04
T3	"	"	"	"					.04
GT Dwg. No. 206-1209B & No. 206-1217B									
T1	A28128	Proprietory	HAT	Sealed					.04
T2	"	"	"	"					.04
GT Dwg. No. 206-1208B									
T1	A28128	Proprietory	"	"					.04
T2	"	"	"	"					.04

FORM 1-9733E (6-61)

FORM 4-13 PART USAGE AND APPLICATION DATA

TRANSISTORS, ALL CLASSES (PAGE 1 OF (2))

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	POWER RATING - MAX* VALUE MW	%Du Cy	@TA or TC (°C)	USAGE - MAXIMA* TA or TC RANGE (°C)	POWERS VALUES mW	%Du Cy	CURRENTS VALUES ma	%Du Cy	VOLTAGES VALUES	%Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
Q1	2N697		600		25		40	a						.0016
Q2	2N1132						8							
Q3	2N697						40							
Q4	2N1132						8							
Q5	2N697						40							
Q6	2N1132						8							
Q7	2N697						40							
Q8	2N1132						8							
Q9	2N697						40							
Q10	2N1132						8							
Q11	2N697						40							
Q12	2N1132						8							
Q13	2N697						8							
Q14	2N1132						40							
Q15	2N697						8							
Q16	2N1132						40							
Q17	2N697						8							
Q18	2N1132						40							
Q19	2N697						8							
Q20	2N1132						40							
Q21	2N697						8							
Q22	2N1132						40							
Q23	2N697						8							
Q24	2N1132						40							
Q25	2N491		450				80	b						.0020
Q26	2N1772A (SCR)						250	c	500				5-7amp.rate	.0016
Q27	2N491		450				80	d						.0020
Q28	2N1772A (SCR)						250	e	500				5-7amp.rate	.0016

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753N (8-61)

FORM 4-13 PART USAGE AND APPLICATION DATA

TRANSISTORS, ALL CLASSES (PAGE 2)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING______ WIRING DIAGRAM______ SCHEMATIC DIAGRAM______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	POWER RATING - MAX* VALUE mw	%Du Cy	@TA or TC (°C)	USAGE - MAXIMA* TA or TC RANGE (°C)	POWERS VALUES mw	%Du Cy	CURRENTS VALUES ma	%Du Cy	VOLTAGES VALUES	%Du Cy	ADD'L REF. CURRENT RATING	FAILURE RATE %/1000 HOURS
Q29	2N491		450		25		80	e						.0020
Q30	2N1772A (SCR)						250	f	500				5-7amp. rat.	.0016
Q31	2N491		450				157	100						.0028
Q32	2N1772A (SCR)						250	g	500				5-7amp.	.0016
Q33	2N1772A (SCR)						250	g	500					.0032
Q34	2N491		450				157	100						.0056
Q35	2N1772A (SCR)						250	g	500				5-7amp.	.0032
Q36	2N1132		600				23	h						.0016
Q37	2N697						240	h						.0016
Q38	2N697						9	100						.0016
Q39	2N1132						270	100						.0033
Q40	2N491		450				157	J						.0016
Q41	2N1772A (SCR)						250	K	500				5-7amp.	.0016
Q42	2N491		450				157	100						.0028
Q43	2N1772A (SCR)						250	K	500				5-7amp	.0016
Q44	2N491		450				157	100						.0028
Q45	2N1772A (SCR)						250	K	500				5-7amp.	.0016
Q46	2N491		450				157	L						.0016
Q47	2N1772A (SCR)						250	m	500				5-7amp.	.0016
Q48	2N491		450				157	100						.0028
Q49	2N1772A (SCR)						250	m	500				5-7amp	.0016
Q50	2N491		450				157	100						.0028
Q51	2N1772A (SCR)						250	m	500				5-7amp	.0016
Q														
Q														
Q														
Q														
Q														

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

TOTAL → .0917

FORM 1-9753N (8-61)

PART 4-4 PART USAGE AND APPLICATION DATA
DIODES, SEMICONDUCTOR, ALL CLASSES (PAGE 1 OF (3))

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE MW	RATING % Du Cy	RATING @T_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES MW	POWERS % Du Cy	CURRENTS VALUES	CURRENTS % Du Cy	VOLTAGES VALUES	VOLTAGES % Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
CR1	1N746		400		25		1/8	100						.0011
CR2							1/8							
CR3							1/8							
CR4							1/8							
CR5							1/8							
CR6							1/8							
CR7							1/8							
CR8							1/8							
CR9							1/8							
CR10							1/8							
CR11							1/8							
CR12							1/8							
CR13	1N647		600				1/4	6						
CR14							1/4							
CR15							1/4							
CR16							1/4							
CR17							1/4							
CR18							1/4							
CR19							1/4							
CR20							1/4							
CR21							1/4							
CR22							640	20						
CR23							1/4							
CR24							1/4							
CR25							1/4							
CR26							1/4							
CR27							1/4							
CR28							1/4							
CR29							1/4							
CR30							1/4							

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753D (8-61)

PART 4-4 PART USAGE AND APPLICATION DATA
DIODES, SEMICONDUCTOR, ALL CLASSES (PAGE 2)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE	% Du Cy	@T_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES	POWERS % Du Cy	CURRENTS VALUES	CURRENTS % Du Cy	VOLTAGES VALUES	VOLTAGES % Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
			MW				MW							
CR31	1N647		600		25		1	d						.0011
CR32							640	S					70μs pulse	
CR42							640	[illegible]					[illegible]	
CR43							640	DD					1ms pulse	
CR44							640	ee					70ms pulse	
CR45							640	ff					10μs pulse	
CR46							640	ff					"	.0022
CR47							640	DD					1ms pulse	.0022
CR48							640	gg					10μs pulse	.0022
CR49							19	[illegible]						.0011
CR50							19	[illegible]						
CR51							18	[illegible]						
CR52							18	JJ						
CR53	1N758		400				10	100						
CR54	1N758		400				1.2	100						
CR55	1N647		600				640	T					50μs pulse	
CR56							640	T					"	
CR57							640	T					"	
CR58							72	AA						
CR59														

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9753D (8-61)

PART 4-4 PART USAGE AND APPLICATION DATA
DIODES, SEMICONDUCTOR, ALL CLASSES (PAGE 3)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE MW	RATING % Du Cy	RATING θT_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES MW	POWERS % Du Cy	CURRENTS VALUES	CURRENTS % Du Cy	VOLTAGES VALUES	VOLTAGES % Du Cy	ADD'L REF.	FAILURE RATE %/1000 HOURS
CR60	IN647		600		25		.							.0011
CR61							.							
CR62							24	Y						
CR63							640	✓					50μs pulse	
CR64							640	✓					"	
CR65							640	✓					"	
CR66							72	AA						
CR67							.							
CR68							24	Z						

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-0753D (6-61)

TOTAL → .0759

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PAGE 1) OF (4)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. ±%	POWER RATING WATTS	OPERATING POWER WATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R1	CARBON FILM	MEPCO	10K	10	1/8	1	<10			.0006
R2			1.82K			70	56			.0010
R3			10K			1	<10			.0006
R4			1.82K			70	56			.0010
R5			10K			1	<10			.0006
R6			1.82K			70	56			.0010
R7			10K			1	<10			.0006
R8			1.82K			70	56			.0010
R9			10K			1	<10			.0006
R10			1.82K			70	56			.0010
R11			10K			1	<10			.0006
R12			1.82K			70	56			.0010
R13			10K			1	<11			.0006
R14			1.82K			70	56			.0010
R15			1.82K			70	56			.0010
R16			10K			1	<10			.0006
R17			1.82K			70	56			.0010
R18			10K			1	<10			.0006
R19			1.82K			70	56			.0010
R20			10K			1	<10			.0006
R21			1.82K			70	56			.0010
R22			10K			1	<10			.0006
R23			1.82K			70	56			.0010
R24			10K			1	<11			.0006
R25			432K			.1				
R26						.1				
R27						.1				
R28			1M			.1				
R29	WW	SHALCROSS	25			1/100				.0029

FORM 1-9783 (9-61)

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PAGE 2)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER mWATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R30	CARBON FILM	MEPCO	475		1/8	b 7.6	<10			.0006
R31			20K			BB 9.7				
R32			432 K			d .15				
R33						d .15				
R34						d .15				
R35			1M			d .07				
R36	WW	SHALCROSS	25			S 1100	<10			.0029
R37	CARB. FILM	MEPCO	475			d 7.6	<10			.0006
R38			20K			BB 9.7				
R45			20K			BB 9.7				
R46			511 K			CC 1				
R47			475			100% .15				
R48			10K			G 3.6				
R49	WW	SHALCROSS	10			A 3600	<10			.0029
R50	CARBON FILM	MEPCO	20K			G 9.7	<10			.0006
R51			20K			G 9.7				.0010
R52			511K			CC 1				
R53			10K			G 3.6				
R54			475			100% .15				
R55	WW	SHALCROSS	10			B 3600	<10			.0058
R56	CARBON FILM	MEPCO	20K			G 9.7	<10			.0010
R57	WW	SHALCROSS	1.5K			J 530	<10			.0029

FORM 1-9753J (8-61)

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PAGE 3)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER mW/WATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R58	WW	SHALCROSS	1.5K		1/8	L 530	<10			.0029
R59	CARB. FILM	MEPCO	7.5K			14 100%	11			.0006
R60			22.1K			26 100%	20			.0006
R61			200K			3 100%	<10			.0006
R62			2K			30 100%	24			.0006
R63			274K			BB 2.1	<10			.0006
R64			475			15 100%	12			.0006
R65	WW	SHALCROSS	10			T 3600	<10			.0029
R66	CARB. FILM	MEPCO	20K			J 9.7	<10			.0006
R67	WW	SHALCROSS	5			U 10000	<10			.0029
R68	CARB. FILM	MEPCO	10K			BB 3.6	<10			.0006
R69			475K			BB 1.3	<10			
R70			475			15 100%	12			
R71			20K			J 9.7	<10			
R72			10K			BB 3.6	<10			
R73			475K			BB 1.3	<10			
R74			475			15 100%	12			
R75	WW	SHALCROSS	5			U 10000	<10			.0029
R76	CARB. FILM	MEPCO	20K			J 9.7	<10			.0006
R77	WW	SHALCROSS	1.5K			Y 530	<10			.0029
R78	WW	SHALCROSS	1.5K			Z 530	<10			.0029
R79	CARB. FILM	MEPCO	274K			BB 2.1	<10			.0006
R80	WW	SHALCROSS	10			V 3600	<10			.0029
R81	CARB. FILM	MEPCO	20K			L 9.7	<10			.0006
R82			475			15 100%	12			
R83			340K			BB 2	<10			
R84			10K			BB 3.6	<10			
R85			475			15 100%	12			
R86	WW	SHALCROSS	10			V 3600	<10			.0029

FORM 1-9758J (8-61)

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PAGE 4)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ____ WIRING DIAGRAM ____ SCHEMATIC DIAGRAM ____

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER mWATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R87	CARB. FILM	MEPCO	20K		1/8	L 9.7	<10			.0006
R88	↓	↓	392K		↓	BB 2	<10			.0006
R89	↓	↓	475		↓	15 100%	12			.0006
R90	WW	SHALCROSS	5		↓	X 10000	<10			.0029
R91	CARB. FILM	MEPCO	20K		↓	L 9.7	<10			.0006
R92	CARB. FILM	MEPCO	10K		↓	BB 3.6	<10			.0006
R93	WW	SHALCROSS	280		↓	AA 1430	<10			.0029

FORM 1-9753J (8-61)

TOTAL → 1.0204

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (POT.)

COMPONENT DESIGNATION FCC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER mWATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
	POT.		5K		2	10 100%	<10			.145
						10				
						10				
						10				
						10				
						10				
						10				
						10				
						10				
						10				
						10				
						10				
			50K		1	13 6				
						13 6				
						13 6				
						17 4				
						17 4				
						17 4				
			20K		2	40 100%				
			5K			70				

FORM 1-9769J (8-61)

TOTAL → 3.335

FCC

PART USAGE AND APPLICATION DATA

CAPACITORS

COMPONENT DESIGNATION: CKT. SYMB. NO.	COMPONENT DESIGNATION: TYPE NO. (GE, MIL OR VENDOR)	ASSEMBLY DRAWING: MFR.	CAP. VALUE MFD.	TOL. %	RATED VOLTAGE	WIRING DIAGRAM: OPERATING VOLTAGE	% OPERATED TO RATED VOLTAGE	OPERATING AMBIENT TEMP. °C	SCHEMATIC DIAGRAM: CIRCUIT FUNCTION OR APPLICATION	FAILURE RATE % 1000 HOURS
C1	150D TANT.	SPRAGUE								
C2										
C3			1.5		20	12 b	60			.009
C4			47		35	35 LL	100			.030
C5			1.5		20	12 d	60			.009
C6			47		35	35 mm	100			.030
C8			47		35	35 NN	100			.030
C9			2.2		20	19 PP	95			.025
C10			47		35	35 RR	100			.030
C11			47		35	35 RR	100			.030
C12			2.2		20	19 PP	95			.025
C13			47		35	35 PP	100			.030
C15	150D		2.2		20	19 J	95			.025
C16			47		35	35 J	100			.030
C17			100		20	19 aa	95			.025
C18			47		35	35 J	100			.030
C19			100		20	19 aa	95			.025
C20			47		35	35 J	100			.030
C21			1		35	28 100%	80			.015
C22			1		35	28	80			.015
C23			1		35	28	80			.015
C24			2.2		20	19 L	95			.025
C25			47		35	35 L	100			.030
C26			2.2		20	19 L	95			.025
C27			47		35	35 L	100			.030
C28			39		20	19 AA	95			.025
C29			47		35	35 L	100			.030
C30			1		35	28 100%	80			.015
C										
C										
C										
C										
C										
										.662

FORM 1-9753A REV. (11-61)

FORM 4-8 PART USAGE AND APPLICATION DATA

RELAYS

COMPONENT DESIGNATION FCC   ASSEMBLY DRAWING ____   WIRING DIAGRAM ____   SCHEMATIC DIAGRAM ____   (10^{-6}/MISSION) N/A

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	CONTACT CURRENT RATING	OPERATING CONTACT CURRENT ma	TYPE OF LOAD (RESIS., IND., LAMP, OTHER)	OPEN CONTACT VOLTAGE	% OPERATED TO RATED CURRENT	TOTAL OPERATIONS	CONTACT SET	FAILURE RATE
K1	JRC-1C-12C	BRANSON		.13				336 MAX	1	58.80
K2				.13						
K3				.13						
K4				.13						
K5				.13						
K6				.13				(4 EVERY 2 HRS.)		
K7				.13						
K8				.13						
K9				.13						
K10				.13						
K11				.13						
K12				.13						
K13	JRC-1C-26.5C			.13				252 MAX.		44.10
K14	BR9 AX-G3-V2	BABCOCK		1000					2	88.20
K15				1.7						
K16				18						
K17				1120				1		.350
K18				2000				70		24.50
K19				2000				70		24.50
K20				18				336 MAX.		117.60
K21				2000						
K22				1.7						

FORM 1-9753H (8-61)

1416.45

FORM 4-13 PART USAGE AND APPLICATION DATA

TRANSISTORS, ALL CLASSES

COMPONENT DESIGNATION FUEL CELL FAILURE DETECTOR ASSEMBLY DRAWING____ WIRING DIAGRAM____ SCHEMATIC DIAGRAM____

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	POWER RATING - MAX*			USAGE - MAXIMA*								FAILURE RATE %/1000 HOURS
			VALUE MW	%Du Cy	@TA or TC (°C)	TA or TC RANGE (°C)	POWERS VALUES MW	POWERS %Du Cy	CURRENTS VALUES	CURRENTS %Du Cy	VOLTAGES VALUES	VOLTAGES %Du Cy	ADD'L REF. RATING %	
Q1	2N697		600		25		40	a					<10	.0016
Q2	2N1132						8							
Q3							8							
Q4							8							
Q5							8							
Q6							8							
Q7							8							
Q8							40							
Q9							40							
Q10							40							
Q11							40							
Q12							40							
Q13	2N697						8							

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE. .0208

FORM 1-9753N (8-61)

PART 4-4 PART USAGE AND APPLICATION DATA
DIODES, SEMICONDUCTOR, ALL CLASSES

COMPONENT DESIGNATION FUEL CELL FAILURE DETECTOR ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RATING (PWR. or CURR. MAX*) VALUE mW	RATING % Du Cy	RATING @T_A or T_C (°C)	USAGE-MAXIMA* T_A or T_C RANGE (°C)	POWERS VALUES mW	POWERS % Du Cy	CURRENTS VALUES	CURRENTS % Du Cy	VOLTAGES VALUES	VOLTAGES % Du Cy	ADD'L REF. RATING	FAILURE RATE %/1000 HOURS
CR1	1N746		400		25		18	100					<10%	.0011
CR2							18							
CR3							18							
CR4							18							
CR5							18							
CR6							18							
CR7							18							
CR8							18							
CR9							18							
CR10							18							
CR11							18							

* LIST CONDITIONS FOR EACH ELEMENT SEPARATELY, AS APPLICABLE.

FORM 1-9752D (8-61)

.0121

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PAGE 1)

COMPONENT DESIGNATION FUEL CELL FAILURE DETECTOR ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER mWATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
R1	CARBON FILM	MEPCO	1.8K		1/8	69	56			.0010
R2			1K			.16	<10			.0006
R3			1.8K			69	56			.0010
R4			2K			.32	<10			.0006
R5			1.8K			69	56			.0010
R6			3K			.48	<10			.0006
R7			1.8K			69	56			.0010
R8			4K			.64	<10			.0006
R9			1.8K			69	56			.0010
R10			5K			.80	<10			.0006
R11			1.8K			69	56			.0010
R12			6K			.96	<10			.0006
R13			1.8K			69	56			.0010
R14			4K			4	<10			.0006
R15			1.8K			69	56			.0010
R16			3.2K			3.2	<10			.0006
R17			1.8K			69	56			.0010
R18			2.4K			2.4	<10			.0006
R19			1.8K			69	56			.0010
R20			1.6K			1.6	<10			.0006
R21			1.8K			69	56			.0010
R22			800Ω			.8	<10			.0006
										.0176
	POT.		5K		1	10 100%	<10			.145
						10				
						10				
						10				
						10				
						10				
						10				

FORM 1-9753J (8-61)

FORM 4-9 PART USAGE AND APPLICATION DATA

RESISTORS (PG.2)

COMPONENT DESIGNATION FUEL CELL FAILURE DETECTOR ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	RES. VALUE OHMS	TOL. %	POWER RATING WATTS	OPERATING POWER M WATTS	% OPERATING TO RATED POWER	OPERATING AMBIENT TEMP °C	CIRCUIT FUNCTION	FAILURE RATE %/1000 HOURS
	POT.		5K		1	10 100% 10 10 10	<10			.145 1.595

FORM 1-9783J (8-61)

FORM 4-8 PART USAGE AND APPLICATION DATA

RELAYS

COMPONENT DESIGNATION FSSC ASSEMBLY DRAWING ______ WIRING DIAGRAM ______ SCHEMATIC DIAGRAM ______ $N\lambda$ (10^{-6}/MISSION)

CKT SYMB NO.	TYPE NO. (GE, MIL or VENDOR)	MFR.	CONTACT CURRENT RATING	OPERATING CONTACT CURRENT ma	TYPE OF LOAD (RESIS., IND., LAMP, OTHER)	OPEN CONTACT VOLTAGE	% OPERATED TO RATED CURRENT	TOTAL OPERATIONS	SET CONTACTS	FAILURE RATE %/10,000 OPERA-TIONS
K1	JRC-1C-12C	BRANSON	12.	.13				(1)	1	.175
K2	JRC-1C-12C	BRANSON	12.	.13				(1)	1	.175
										.350

FORM 1-9753H (8-61)

1. Ambient temp for FCC and FSSC $70^{o}F$ - $150^{o}F$ cyclic

2. Duty cycles for FCC and FSSC parts

   a) typical time for a group of 3 cells to remain under voltage

   b) typical time for a fuel cell module to remain below $140^{o}F$

   c) random, pulse width 10 ms

   d) typical time for a fuel cell module to stay above $125^{o}F$ after it has reached $140^{o}F$ and had its load removed

   e) typical life of a fuel cell module

   f) once per flight

   g) 1 pulse every 18 seconds for 10 minutes, then once per flight - pulse width 10 ms

   h) typical time for a fuel cell module to remain under voltage

   j) 1 sec pulse every 30 sec but not more than 4 per 2 hours

   k) 10 ms pulse every 30 sec, but not more than 4 per 2 hours

   l) 1 sec pulse every 30 sec, but not more than 4 per 2 hours

   m) 10 ms pulse every 30 sec, but not more than 4 per 2 hours

   n) 70 μs pulse width every time FC module goes from $<140^{o}F$ to $>140^{o}F$

   p) 70 μs pulse width once per flight

   r) 50 μs pulse once every 18 sec for 10 minutes

   s) 70 μs pulse width every time FC module goes below $125^{o}F$ after it reached $140^{o}F$ and dumped its load

   t) 50 μs pulse width every 30 sec but not more than 4 per 2 hours

   u) 500 μs pulse width every 30 sec but not more than 4 per 2 hours

   v) 50 μs pulse width every 18 sec but not more than 8 per 2 hours

   x) 500 μs pulse width every 18 sec but not more than 8 per 2 hours

   y) 2 ms pulse width every 90 sec but not more than 6 per 2 hours

   z) 2 ms pulse width every 18 sec but not more than 8 per 2 hours

   AA) 51 ms pulse width once every 2 hours

   BB) random

   CC) 1 pulse every 18 sec for 10 min pulse width 1 sec

   DD) 1 ms pulse width - cycle to be determined by ground test

APPENDIX 2C

FUEL CELL CONTROL ELECTRONICS DETAILED TEST PROCEDURES AND DATA

APPENDIX 2C. FUEL CELL CONTROL ELECTRONICS DETAILED TEST PROCEDURES AND DATA

A. VOLTAGE SENSORS

Both the circuit shown in Figure 1 and its complement were checked for excessive semiconductor and relay power dissipation and case temperatures at various conditions of ambient temperature and input voltage. The circuits were mounted on vector boards with thermocouples connected to all transistor cases, and put into a standard laboratory temperature chamber. The circuits were allowed 10 minutes to stabilize at each condition before measurements were taken. The experimental values and the maximum ratings are shown in Table 1. In addition the circuit of Figure 1 was checked for drift of input voltages required to initiate a purge with respect to temperature and B^+ voltage. As before, both circuits were allowed 10 minutes to stabilize at each test condition before measurements were taken. The results are shown in Table 2.

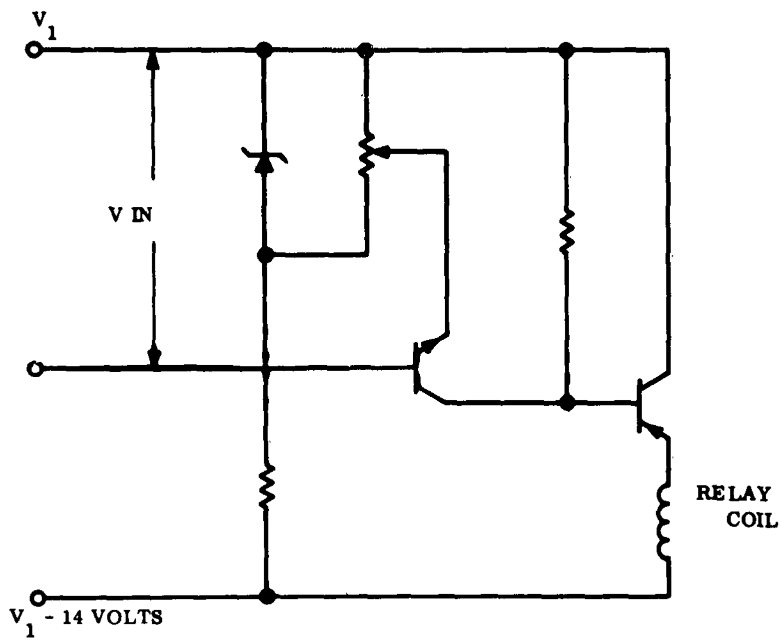


Figure 1. Voltage Sensor (PNP Relay Drive)

B. 20 VOLT SERIES REGULATOR

The 20 volt series regulator shown in Figure 2 was checked, with maximum load on the output, for excessive semiconductor power dissipation and case temperatures at various conditions of ambient temperature and input voltage. The circuit was mounted on a vector board with thermocouples connected to all transistor cases and put into a standard laboratory temperature chamber. The circuit was allowed 10 minutes to stabilize at each condition before measurements were taken. The experimental values and the maximum ratings are shown in Table 3. In addition, regulation data was taken at various conditions of input voltage and ambient temperatures. As before, the circuit was allowed 10 minutes to stabilize at each test condition before measurements were taken. The results are shown in Table 4.

TABLE 1. VOLTAGE SENSOR POWER DISSIPATION DATA

Maximum Power Ratings @ 75°C

NPN 1333 mw
PNP 1333 mw

Maximum Power Ratings @ 75°C Ambient

Zener Diode 280 mw

Maximum Operating Temperature

Relay 125°C

NPN RELAY DRIVE

Ambient Temp. °C	V in Volts	Power mw Sensing Transistor	Case Temp Sensing Transistor °C	Power mw Relay Drive Transistor	Case Temp Relay Drive Transistor °C	Power mw Zener Diode
-17	2.1	2.8	-16	107	-16	5.6
	1.8	4.7	-15	39	-15	5.4
	1.5	4.2	-15	39	-15	4.8
	1.3	3.4	-17	39	-15	4.4
+18	2.1	6.9	+25	39	+27	5.8
	1.8	5.5	+25	39	+27	5.2
	1.5	4.3	+25	39	+27	4.6
	1.3	3.1	+25	39	+27	4.2
+65	2.1	8.1	+63	39	+70	5.6
	1.8	5.9	+63	39	+70	5.0
	1.5	4.2	+68	39	+70	4.4
	1.3	3	+68	39	+70	4

PNP RELAY DRIVE

Ambient Temp. °C	V in Volts	Power mw Sensing Transistor	Case Temp Sensing Transistor °C	Power mw Relay Drive Transistor	Case Temp Relay Drive Transistor °C	Power mw Zener Diode	Relay Case Temp °C
-17	2.1	3.3	-16	175	-15	5.7	3
	1.8	4.7	-16	39	-16	5.2	12
	1.5	4.1	-16	39	-16	4.8	13
	1.3	3.2	-16	39	-16	4.4	13
+18	2.1	3.6	+25	39	+25	5.5	50
	1.8	4.9	+25	39	+25	5.1	51
	1.5	3.8	+25	39	+25	4.6	52
	1.3	3	+25	39	+25	4.1	51
+65	2.1	5.2	+72	31	+65	5.3	93
	1.8	5.5	+70	31	+68	4.9	94
	1.5	4	+70	31	+68	4.4	94
	1.3	2.7	+70	31	+68	4.0	94

TABLE 2. DRIFT OF INPUT VOLTAGE REQUIRED TO INITIATE A PURGE WITH RESPECT TO TEMPERATURE AND B^+ DATA

Ambient Temp. ^{o}C	B^+	in required to initiate a purge, volts
25	14	2.0968
	13	2.0452
	12	1.9999
	11	1.9492
	10	1.8779
50	14	2.0962
	13	2.0555
	12	2.0099
	11	1.9510
	10	1.8927
75	14	2.1066
	13	2.0664
	12	2.0203
	11	1.9655
	10	1.9045

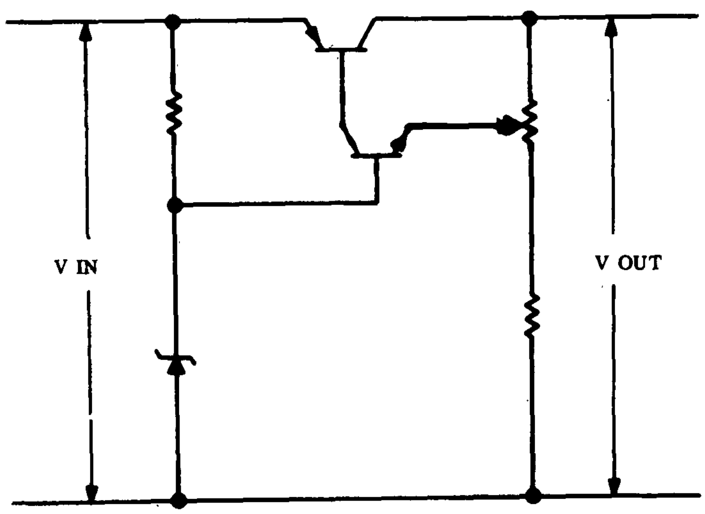


Figure 2. 20 Volt Series Regulator

TABLE 3. 20 VOLT SERIES REGULATOR POWER DISSIPATION DATA

Maximum Power Ratings @ 75°C Case Temp.

NPN 1333 mw
PNP 1333 mw

Maximum Power Rating @ 75°C Ambient
Zener Diode 280 mw

Ambient Temp °C	V in Volts	Power mw PNP Transistor	Case Temp °C PNP Transistor	Power mw NPN Transistor	Case Temp °C NPN Transistor	Power mw Zener Diode
25	20	37	28	7.3	28	1
	28	131	28.5	4	27	1
	33	250	36	7.2	29	1
50	20	38	50	8	50	1
	28	117	50	3.9	50	1
	33	250	55	6.7	55	1
75	20	40	75	8.7	75	1
	28	111	75	3.7	75	1
	33	245	75	6.3	75	1

TABLE 4. REGULATION DATA

V in Volts	25°C ambient		50° ambient		70° ambient	
	V out Volts	I out ma	V out Volts	I out ma	V out Volts	I out ma
20	19.6	0	19.6	0	19.6	0
	19.1	4.9	19.1	4.9	18.9	4.9
	19.0	5.3	19	5.3	18.9	5.3
	18.9	6.3	19	6.4	18.9	6.3
	18.8	7.3	18.8	7.3	18.8	7.3
	18.7	9.4	18.7	9.4	18.6	9.3
	18.3	12.2	18.3	12.2	18.3	12.2
	17.7	17.7	17.7	17.7	17.7	17.7
28	21	0	21.5	0	22	0
	20.8	5.3	21.3	5.5	21.8	5.7
	20.5	6.2	21.2	6.4	21.8	6.6
	20.5	9.3	21.0	9.6	21.5	9.78
	20.3	11.2	20.9	11.6	21.3	11.8
	20.3	13.5	20.8	13.8	21.3	14.2
	20	20	20.5	20.5	20.8	20.8
33	20.8	0	21.2	0	21.5	0
	20.4	5.2	20.8	5.4	21.2	5.4
	20.4	5.7	20.8	5.8	21.1	5.9
	20.3	6.8	20.8	6.9	21.1	7.0
	20.2	7.7	20.6	7.9	21	8.1
	20.1	10	20.5	10.4	20.9	10.4
	19.9	13.3	20.3	13.6	20.7	13.8
	19.5	19.5	20	20	20.4	20.4

C. TOTAL MODULE UNDERVOLTAGE SENSOR

The test procedures and conditions for this subcircuit, with the exception of the input voltage, should be similar to the group voltage sensor format. The exception being that the input voltage should be varied between 20 and 33 volts.

D. TEMPERATURE SENSOR

The temperature sensor circuit should be checked to determine the change of fuel cell temperature to perform its switching function with respect to B^+ and ambient temperature. A multi-turn potentiometer, mounted outside of the test chamber, should be used to simulate the fuel cell thermistor, while the curve in Figure 3 should be used to translate simulated thermistor resistance into fuel cell temperature. The test conditions should be at ambient temperatures of 25°C, 50°C, and 70°C, and at a B^+ range of 20 volts ±1 volt. In addition, the subcircuit should be adjusted so that it is just in its quiescent state, and subjected to both a source of electromagnetic noise similar to the type and level expected in flight, and to a number of thermal cycles to determine switching stability.

Due to the low dissipation constant of the thermistors selected for use in the DTV temperature sensor, the following procedure should be followed to obtain the necessary calibration data for proper adjustment of the control operating points and calculation of the output voltage versus temperature characteristics. Because the thermistors to be used in the 180°F fuel supply cutoff circuit cannot be calibrated after installation in the fuel cell, the thermistors are to be connected as shown in Figure 4 with R_s = 20 KΩ , 25 turn potentiometer in a still air ambient. With the circuit deenergized raise the ambient temperature to 180°F and stabilize. After temperature stabilization, apply power. Slowly reduce R_s until the thermistor voltage stabilizes at 8 ±0.1 volts. Record resistance value of R_s as shown in Table 4 to within ±1% accuracy or better.

After fuel cell installation of the 140°F sensing thermistors, the units are to be connected in the circuit shown in Figure 4 with R_s = 50KΩ, 25 turn potentiometer. With power removed and R_s set at maximum resistance the fuel cell modules are to be placed in a 140°F ambient temperature and allowed to stabilize. After stabilization, apply power and slowly reduce R_s until the thermistor voltage stabilizes at 8 volts ±.1 volt. Remove R_s and record its resistance as shown in Table 5 to within a ±1% accuracy or better.

Repeat the above procedure for the 125°F sensing thermistors, with the exceptions that the fuel cell module should be placed in a 125°F ambient temperature and the thermistor stabilization voltage should be 12 volts, ±.1 volt.

Obtain individual calibration data of thermistor voltage versus fuel cell module temperature as shown in Table 6 with the connections as shown in Figure 5. Record data in Table 6.

E. PURGE SEQUENCER

Inductive kick was investigated by energizing the subcircuit and observing the voltage waveform across each relay coil when switched on and off. The typical waveform shown in Figure 6 revealed a maximum value of 5 volts, which appeared as a momentary reverse voltage across the SCR. Since the SCR's have a peak reverse voltage rating of 100 volts, the 5 volt maximum was well within safety limits.

The purge sequencer should also be checked for the change in characteristic time delay with respect to temperature and B^+ at ambient temperatures of 25°C, 50°C and 75°C, and at a range of B^+ from 20 to 33 volts. For this test a standard digital counter may be used by utilizing the UJT base one pulses as trigger pulses.

In addition, the subcircuit should be put in its standby condition, and subjected to electromagnetic noise and thermal cycling similar to the type utilized in the testing of the temperature sensor.

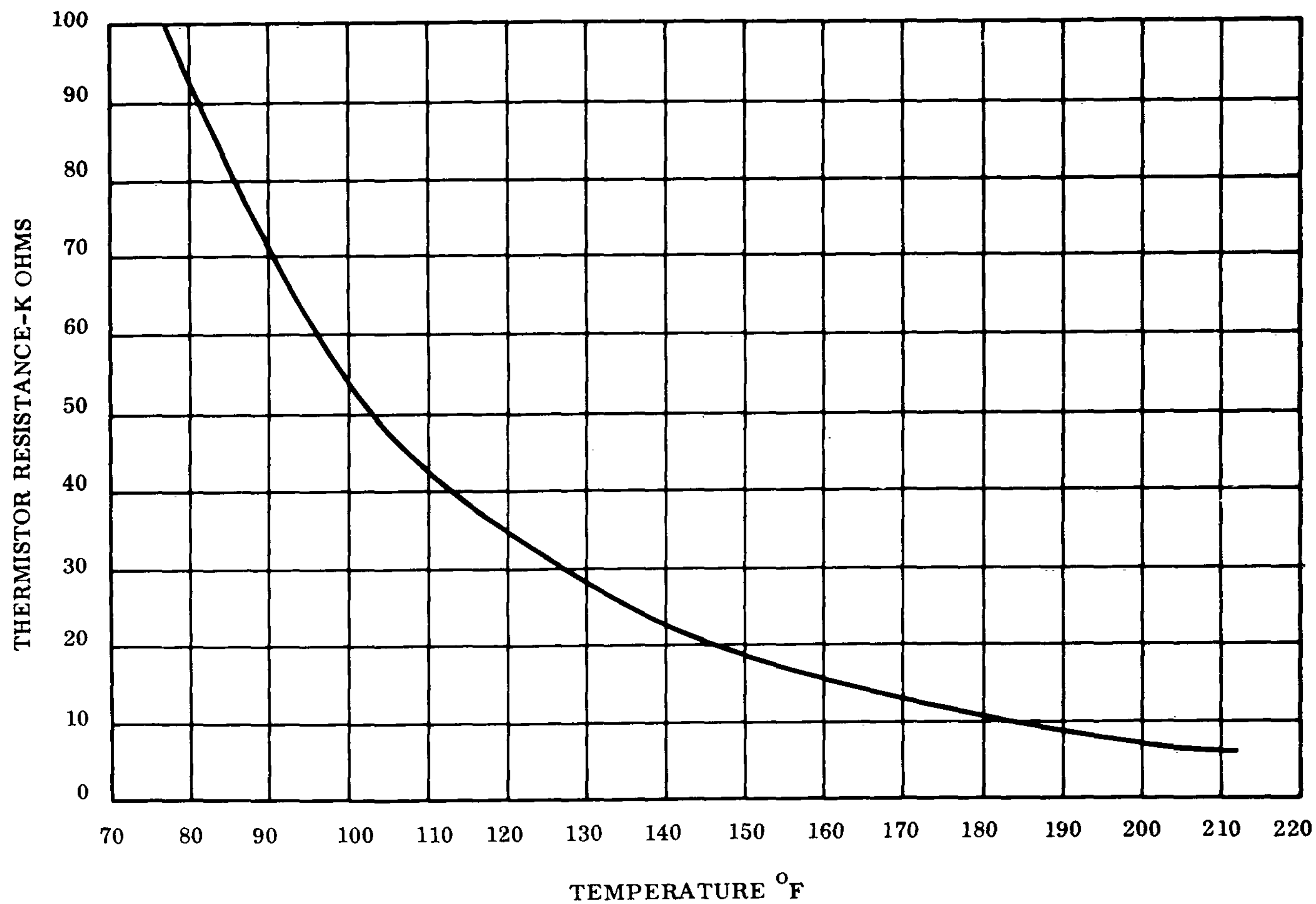


Figure 3. Thermistor Resistance-Temperature Characteristic (Self Heating Included)

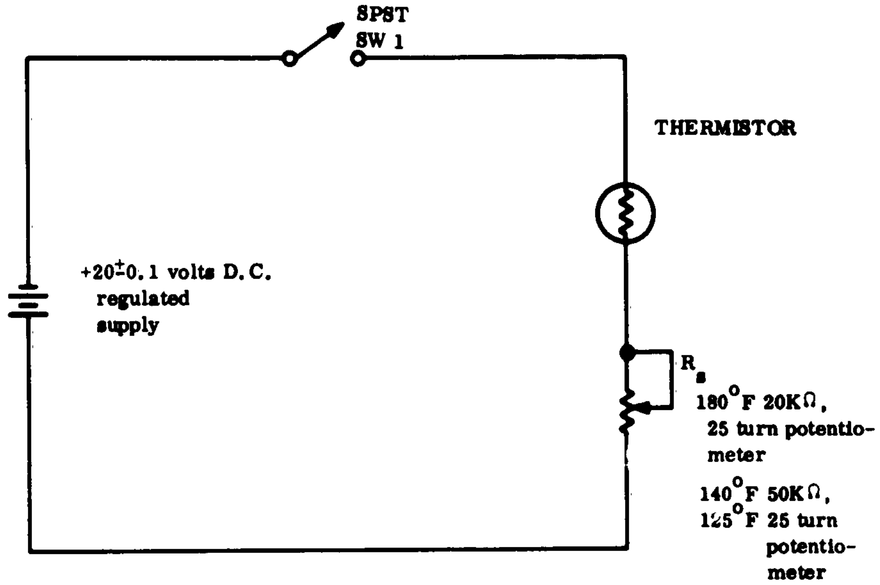


Figure 4. Circuit to Determine Thermistor Series Calibrating Resistor

TABLE 5. TEMPERATURE CONTROL OPERATING POINT CALIBRATION DATA

Fuel Cell Serial No. ____________________

FUEL CELL THERMISTOR		RESISTANCE OF R_s IN K OHMS
1) 180°F		
Pins	RT9	*R_{s1}
	RT8	*R_{s2}
	RT7	*R_{s3}
2) 140°F		
Pins	RT6	R_{s4}
	RT5	R_{s5}
	RT4	R_{s6}
3) 125°F		
Pins	RT3	R_{s7}
	RT2	R_{s8}
	RT1	R_{s9}

*This data to be obtained before fuel cell installation of 180°F sensing thermistors. See Paragraph (2).

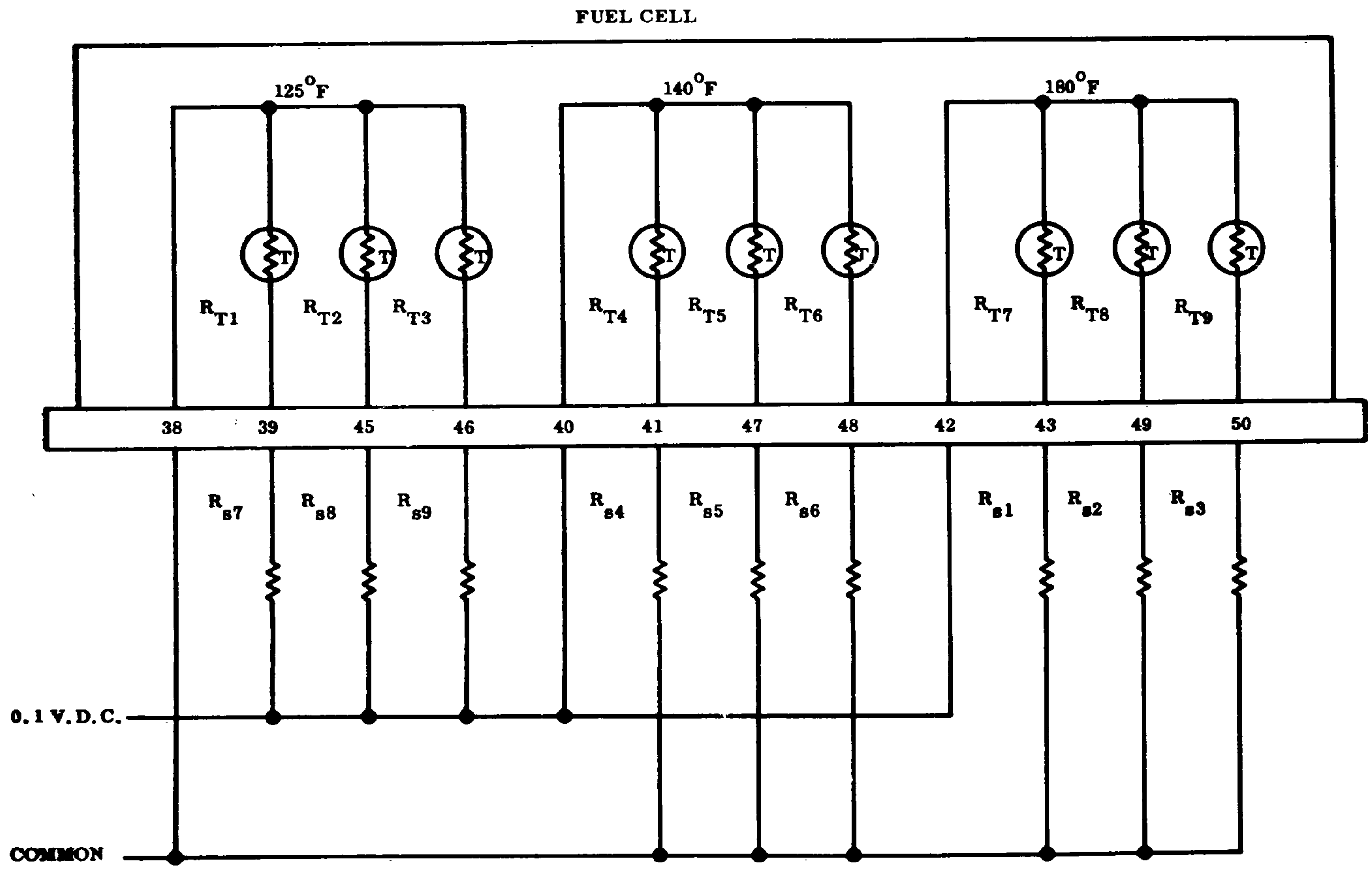


Figure 5. Circuit for Obtaining Thermistor Voltage vs. Fuel Cell Module Temperature Data

TABLE 6. VOLTAGE VERSUS TEMPERATURE CALIBRATION DATA

Fuel Cell Serial No.________________________

FUEL CELL THERMISTOR		THERMISTOR VOLTAGE*								
		35^oF	55^oF	80^oF	100^oF	120^oF	125^oF	130^oF	135^oF	140^oF
1) 125^oF										
Pins	RT1									
	RT2									
	RT3									
2) 140^oF										
Pins	RT4									
	RT5									
	RT6									
3) 180^oF										
Pins	RT7									
	RT8									
	RT9									

*This data to be obtained at the indicated fuel cell module temperatures.

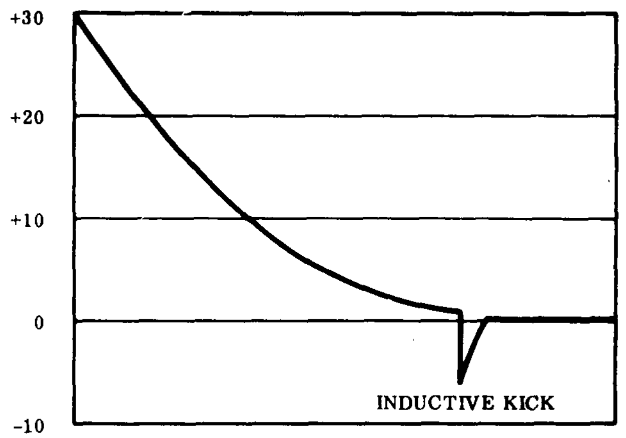


Figure 6. Voltage Waveform Across Relay Coil When Switched On and Off by SCR

F. SOLENOID VALVE SWITCH

The solenoid valve switching circuit shown in Figure 7, was investigated for contact arcing and inductive kick by utilizing the actual pneumatic valves for the test. By placing .1 Ω current sampling resistors in series with the capacitor and diode, the current wave shapes in these branches were found. By graphically subtracting the capacitor branch current from the diode branch current in Figure 8 the relay contact current shown in Figure 9 was found. The maximum contact current of .6 amps was less than the maximum rated contact current of 1 amp. Figure 10, the solenoid valve voltage wave shape, indicates a maximum inductive kick of 3 volts.

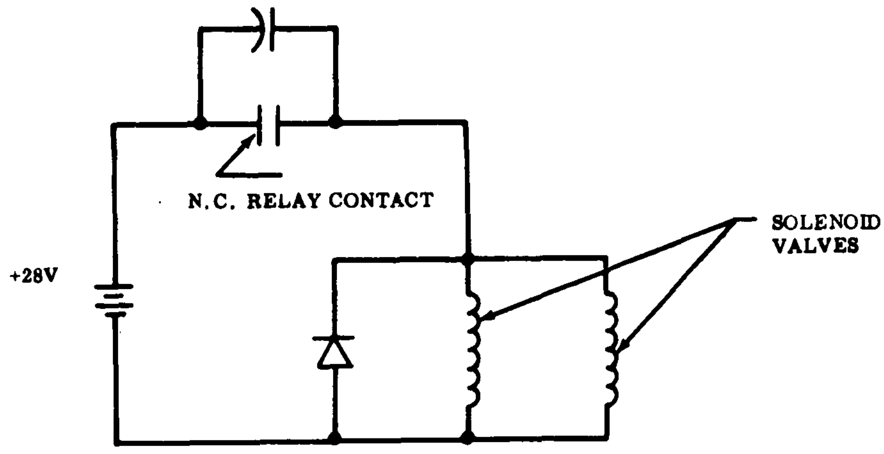


Figure 7. Solenoid Valve Switching Circuit

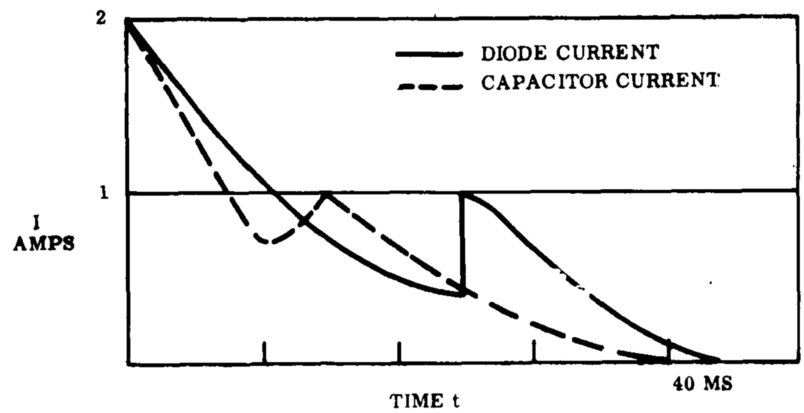


Figure 8. Relay Contact Current

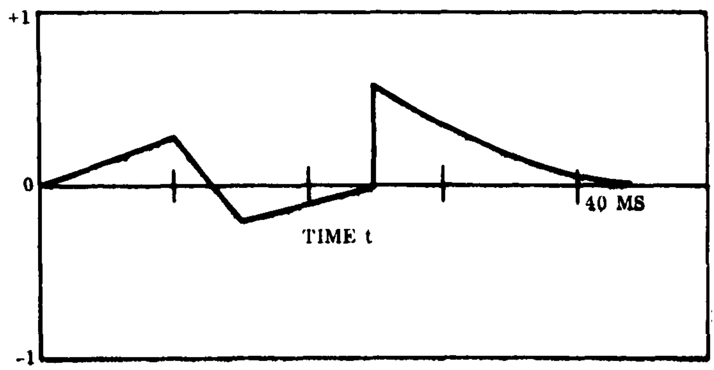


Figure 9. Relay Contact Current

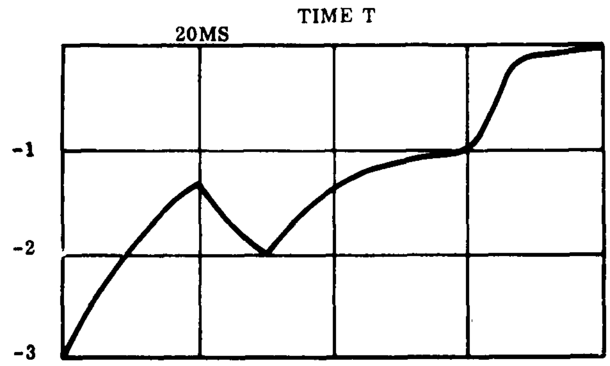


Figure 10. Solenoid Valve Voltage Waveshape When Switched Off

G. GENERAL ELECTRIC RELAY DRIVE TIMING SYSTEM

DESCRIPTION

The General Electric Relay Drive Timing System consists of seven General Time logic modules, an external SCR drive circuit and four Babcock relays. It is the intended purpose of the above composite logic to "drive" the four relays into a particular state at a given time from an initial "To".

The seven General Time logic modules are

1. G. T. Part No. 210-1192 Oscillator-Amplifier Module
2. G. T. Part No. 210-1193 Divide by 200 Module
3. G. T. Part No. 210-1196 Divide by 4 Module
4. G. T. Part No. 210-1194 Purge Counter Module
5. G. T. Part No. 210-1213 Purge Counter Module
6. G. T. Part No. 210-1195 Driver Module
7. G. T. Part No. 210-1195 Driver Module

(Reference Figure 11.)

At "To" power is applied to the oscillator-amplifier module (Part No. 210-1192). At "To" +9 seconds the divide by 200 module (Part No. 210-1193) will receive its first input pulse. This module will receive pulses every nine seconds thereafter until two hundred pulses later (30 minutes) the divide by 200 module will deliver to the divide by 4 module (Part No. 210-1196) an input pulse. At "To" +120 minutes, the divide by 4 module will have received four input pulses. At this time two SCR drive circuits will be actuated (the drive circuit internal to the divide by four module and the external SCR drive circuit) and the purge counters will be reset. Each of these drive circuits will in turn drive two relays to a "predetermined state."

In insure that the relays are not in the "predetermined state" at "To," Purge Counter modules (Part Nos. 210-1213, 210-1194) activate Driver Modules to place the relay in a state other than the predetermined.

External Reset of the divider modules are provided such that the initiation of system operation at "To" can be insured.

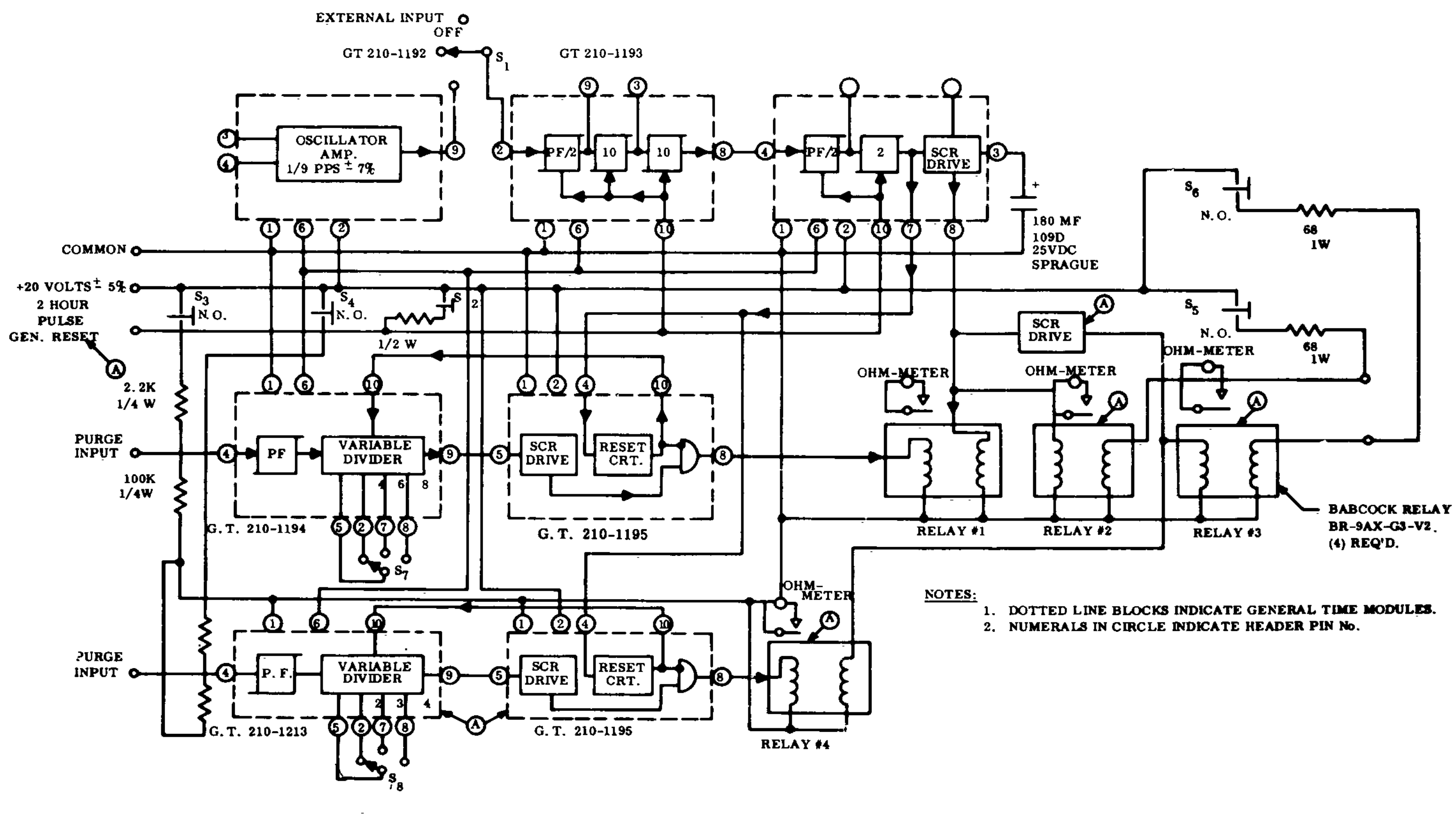


Figure 11. System Logic and Wiring Diagram

External operation of the relays to the predetermined state is provided on the divide by 4 module. With the feature just mentioned and the use of the purge counter modules, it is obvious that the relays can also be controlled independent of other system operation.

TEST PROCEDURE

1.0 Operation

Note: Insure that the power supply is turned down to zero output.

1.1 Interconnect the system as shown in Figure 11.

1.2 Place S_1 to the OFF position.

1.3 Set Power Supply output to 20 volts. Repeat oscillator-amplifier test as outlined in test procedure for G. T. Part No. 210-1192.

1.4 Pulse Generator

1.4.1 Frequency - 10 cps
1.4.2 Pulse Width - 8 μ sec.
1.4.3 Amplitude - 6 volts

1.5 Place S_1 to external input. In approximately 80 seconds the relays will close (note ohmmeters), and the purge counters should be reset.

1.6 Place S_1 to OFF.

1.7 Depress S_5, S_6. Relays 2 and 3 will open.

1.8 Depress S_2 and release instantaneously. The divider modules should now be reset.

1.9 Place S_1 to oscillator-amplifier out and at the same instant start your timing cycle. This is "To."

1.10 Place S_7 in the divide by 8 position. Place S_8 in the divide by 4 position. Within the next hour place 8 pulses in the 210-1194 module by depressing S_3 eight times. At the eight depression relay one should open. In this same time interval place 4 pulses in the 210-1213 module by depressing S_4 four times. At the fourth depression relay four should open.

1.11 Place S_7 in the divide by 6 position. Place S_8 in the divide by 3 position. Within the next half hour place 5 pulses (by depressing S_3 five times) in the 210-1194 module and 2 pulses (by depressing S_4 two times) in the 210-1213 module.

1.12 At "To" + 120 ±7% relays 1 through 4 shall close. At "To" + 121 ±7% insert 6 pulses into module 210-1194, 3 pulses into module 210-1213. Relays 1 and 4 shall open.

1.13 Depress S_5, S_6. Relays 2 and 3 shall open.

1.14 Record data in Table 7.

TABLE 7. RELAY DRIVE TIMING SYSTEM TEST DATA

Purge Counter-Timer System Test Data Summary

System 1	System 2	System 3
GT 210-1192, S.N. 445	S.N. 449	S.N. 450
GT 210-1193, S.N. 446	S.N. 452	S.N. 451
GT 210-1194, S.N. 444	S.N. 454	S.N. 453
GT 210-1195, S.N. 447	S.N. 455	S.N. 456
GT 210-1196, S.N. 448	S.N. 457	S.N. 458

System	Input Voltage	Temperature/Soak Time	Counter Output Purge Holdoff *Relay Operate	Period	Timer 2 Hour Output Purge Holdoff Relay Reset**	Purge Counter Reset
1	20V.	+22°C/--	Oper.	119 min. 8 sec.	Reset	Reset
1		-55°C/1.5 hr.		123 min. 5 sec.		
1		+75°C/3.0 hr.		113 min. 16 sec.		
2		+24°C/--		122 min.		
2		-57°C/1.5 hr.		114 min.		
2		+75°C/1 hr.		122 min.		
3		+28°C/--		120 min.		
3		-57°C/2 hr.		114 min.		
3		+78°C/1 hr.		118 min.		

*Operates One Babcock BR-9AX-G3-V2 relay coil
**Resets two Babcock BR-9AX-G3-V2 relay coils in parallel

OSCILLATOR MODULE PART # 210-1192

Test Procedure

NOTE: Insure power is not applied to unit during the interconnection stage.

1.0 Oscillator Module Part No. 210-1192.

1.1 Interconnect as shown in Figure 12.

1.2 Terminal description: (See Figure 13 for complete module terminal description list and module specification.)

Terminal 1 - Common
Terminal 2 - +20 volts ±10%
Terminal 6 - Regulated output, +11 volts
Terminal 9 - Oscillator output.

2.0 Electronic Counter.

2.1 Function selector - Time interval

2.2 Time unit - 1 KC

2.3 Trigger slope - Positive

2.4 Common-Separate Switch - Common

2.5 Start-Stop Triggering level - +.5 volt

2.6 When properly loaded, the counter will read the oscillator periods in seconds and to the nearest millisecond.

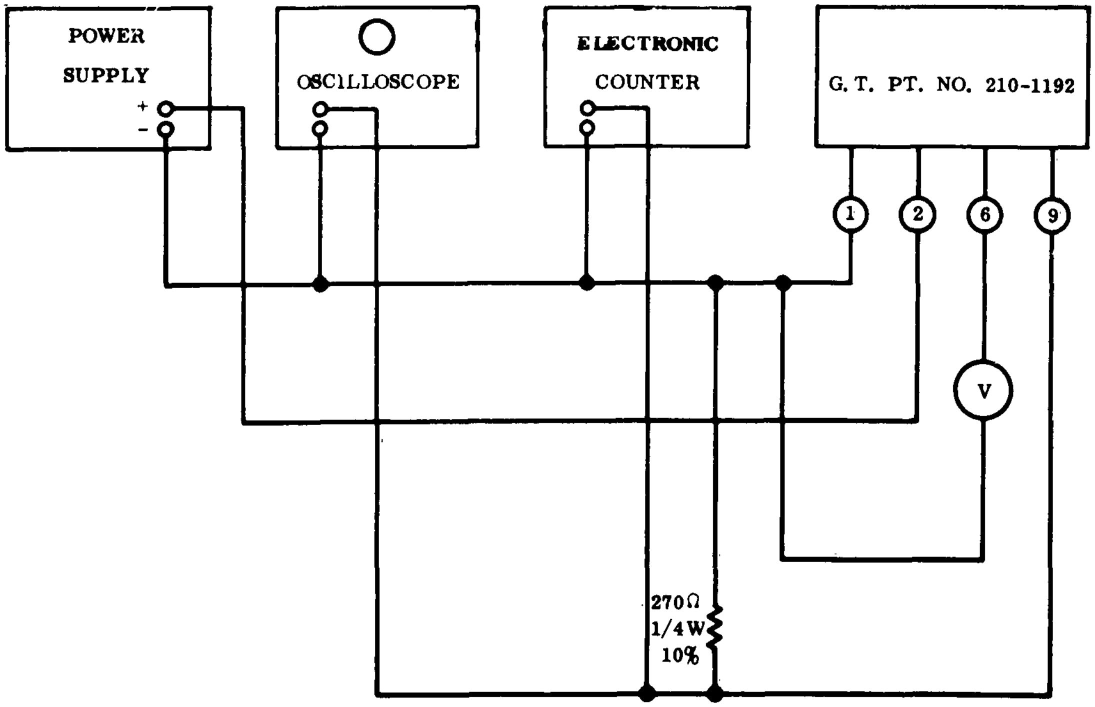
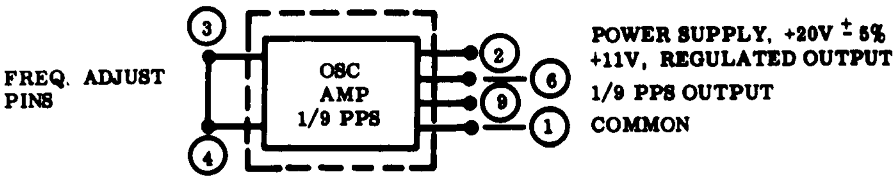


Figure 12. Oscillator Module Interconnection Diagram (Circled Numerals Indicate Module Terminal Numbers)



LOGIC DIAGRAM

NOTES:
1 - PINS 3 & 4 TO BE SHORTED EXTERNAL TO THE CAN WHEN OPERATING AT 1/9 PPS
2 - PINS 3 & 4 TO BE SHORTED AND A TRIM RES. PLACED FROM PIN 3 TO 6 FOR INCREASE IN FREQUENCY. A TRIM RESISTOR SHOULD BE PLACED BETWEEN PIN 3 & 4 TO DECREASE THE FREQUENCY.
3 - NUMERALS IN CIRCLE INDICATE HEADER PIN NO.

PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	POWER SUPPLY +20V ± 5%	
3	FREQUENCY ADJUST PIN	SEE NOTE 2
4	FREQUENCY ADJUST PIN	SEE NOTE 2
5	NOT USED	
6	REGULATED POWER +11V., OUTPUT	
7	NOT USED	
8	NOT USED	
9	OUTPUT 1/9 PPS ± 7%	8 μSEC., 4 VOLTS
10	NOT USED	

Figure 13. Specification Oscillator 1/9 PPS Nom. Module #210-1192

3.0 Oscilloscope.

3.1 Horizontal sweep - 2 μ sec./cm

3.2 Vertical displacement - 2 volts/cm

3.3 Triggering mode - Positive

3.4 Triggering level - Positive

3.5 When properly loaded, terminal 9 will present a 4 ± 1 volt pulse of 8 $\pm 1\mu$ sec. duration every 9 seconds at a supply voltage of 20 volts.

4.0 Power Supply.

4.1 Apply +20 volts to terminal 2, power supply shall vary from 18-22 volts.

5.0 Data.

5.1 As Power Supply is varied from 18-22 volts record,

oscillator period
output pulse width
output pulse amplitude
regulated voltage

200:1 DIVIDER MODULE PART # 210-1193

Test Procedure

NOTE: Insure power is not applied to unit during the interconnection stage.

1.0 200:1 Divider Module Part No. GT 210-1193.

1.1 Interconnect as shown in Figure 14.

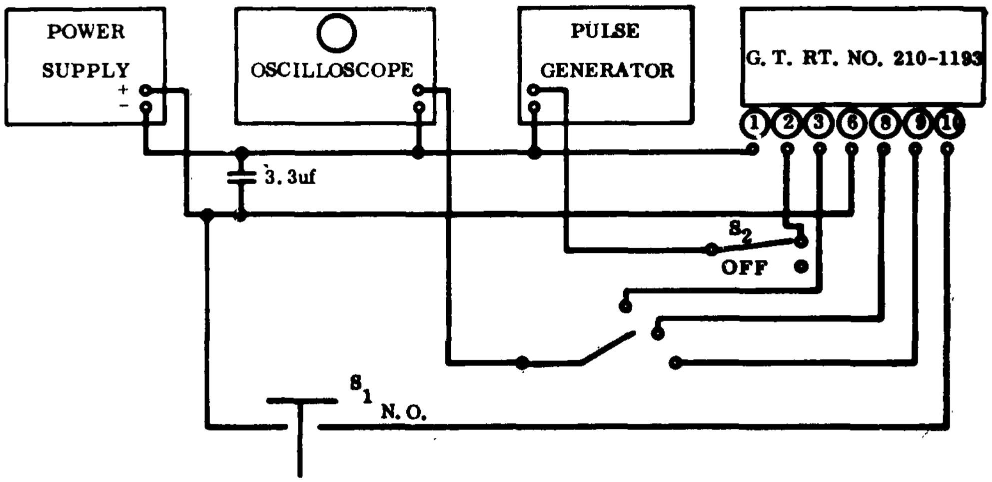


Figure 14. 200:1 Divider Module Interconnection Diagram (Circled Numerals Indicate Module Terminal Numbers)

1.2 **Terminal description.** (See Figure 15 for complete module terminal description list and module specification.)

Terminal 1 - Common
Terminal 2 - Signal input
Terminal 3 - Divide by 20 output
Terminal 6 - +11 volt
Terminal 8 - Divide by 200 output
Terminal 9 - Divide by 2 output
Terminal 10 - Reset

2.0 Divide by 2 output.

2.1 Apply 11 volts to system.

2.2 Pulse generator.

2.2.1 Frequency - 200 cps
Pulse width - 8 μ seconds
Loaded amplitude - 4 volts

2.3 Oscilloscope.

2.3.1 Horizontal sweep - .1 msec./cm

2.3.2 Vertical displacement - 2 volts/cm

2.3.3 Triggering mode - Positive

2.3.4 Triggering level - Positive

2.3.5 Place the scope input to terminal 9 of the divider module. A 100 pps output (pulse every 10 msec.) shall appear. It will be positive going at 4 $\pm$1 volt and 8 $\pm$1 μ sec. The smaller negative pulse is the "count" pulse and should be observed. To determine the character of the output pulse after the frequency has been verified, decrease the horizontal sweep to 2 μ sec./cm and verify 4 $\pm$1 volt at 8 $\pm$1 μ sec.

3.0 Divide by 20 output.

3.1 Pulse generator.

3.1.1 Frequency - 2 KC
Pulse width - 8 μ sec.
Loaded amplitude - +4 volts

3.2 Oscilloscope.

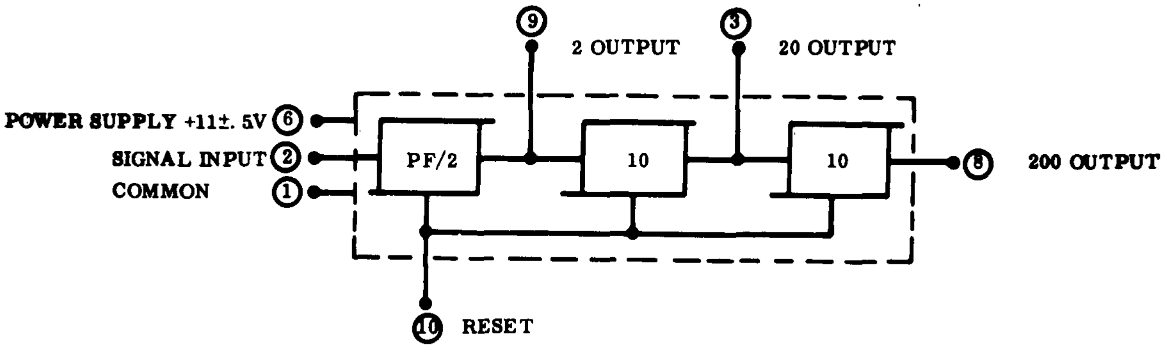
3.2.1 As in 2.3.1 - 2.3.4

3.2.2 Place the scope input to terminal 3 of the divider module. Refer to Paragraph 2.3.5.

4.0 Divide by 200 output.

4.1 Pulse generator.

4.1.1 Frequency - 20 KC
Pulse width - 8 μ sec.
Loaded amplitude - +4 volts



LOGIC DIAGRAM

NOTES:
1 - UNIT INPUT IMPEDANCE 270±10% OHMS
2 - NUMERALS IN CIRCLE INDICATE HEADER PIN NO.

PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	SIGNAL INPUT 20KC MAX	8 ± 1µSEC., 4 ± 1V LOADED
3	÷ 20 OUTPUT	8µSEC., 4 VOLTS
4	NOT USED	
5	NOT USED	
6	POWER SUPPLY +11V ±0.5V	
7	NOT USED	
8	÷200 OUTPUT	8µSEC., 4 VOLTS
9	÷ 2 OUTPUT	8µSEC., 4 VOLTS
10	RESET 10 TO 24V LOADED	50µSEC. TO 0.5 SEC.

Figure 15. Specification Divider 200:1 Module #210-1193

4.2 **Oscilloscope.**

4.2.1 **As in Paragraph 2.3.1 - 2.3.4**

4.2.2 **Place the scope input to terminal 8 of the divider module. Refer to Paragraph 2.3.5.**

5.0 **Reset.**

5.1 **Pulse generator.**

5.1.1 Frequency - 20 cps
Pulse width - 8 μ sec.
Loaded amplitude - +4 volts

5.2 Oscilloscope

5.2.1 Horizontal sweep - 5 μ sec./cm

5.2.2 Vertical displacement - 2 volts/cm

5.2.3 Triggering mode - Positive

5.2.4 Triggering level - Slightly negative

5.2.5 Place the scope input to terminal 8 of the divider module. At the termination of an out pulse (+4 volts at 8 μ sec.) negative pulses of approximately 1 volt at 6-7 μ sec. duration will appear every second. Count out a complete cycle of ten. That is nine negative pulses and the output pulse. Then let the oscilloscope register six pulses. Open S_2 to disconnect the signal input to the module. Depress the reset switch S_1 and release instantaneously. Reconnect the signal input. A count of ten must then be observed to verify reset.

PURGE COUNTER MODULE PART NO'S 210-1194 and 210-1213

Test Procedure

NOTE: Insure power is not applied to unit during the interconnection stage.

1.0 Purge Counter Module Part Nos. 210-1194 and 210-1213.

1.1 Interconnect as shown in Figure 16

1.2 Terminal description: (See Figures 17 and 18 for complete module terminal description list and module specification.)
Terminal 1 - Common
Terminal 2 - Divide by 4 when connected to terminal 5 ($\div$ 2 for 210-1213)
Terminal 4 - Purge input
Terminal 5 - Divider adjust
Terminal 6 - +11 volts
Terminal 7 - Divide by 6 when connected to terminal 5 ($\div$ 3 for 210-1213)
Terminal 8 - Divide by 8 when connected to terminal 5 ($\div$ 4 for 210-1213)
Terminal 9 - Divider output
Terminal 10 - Reset

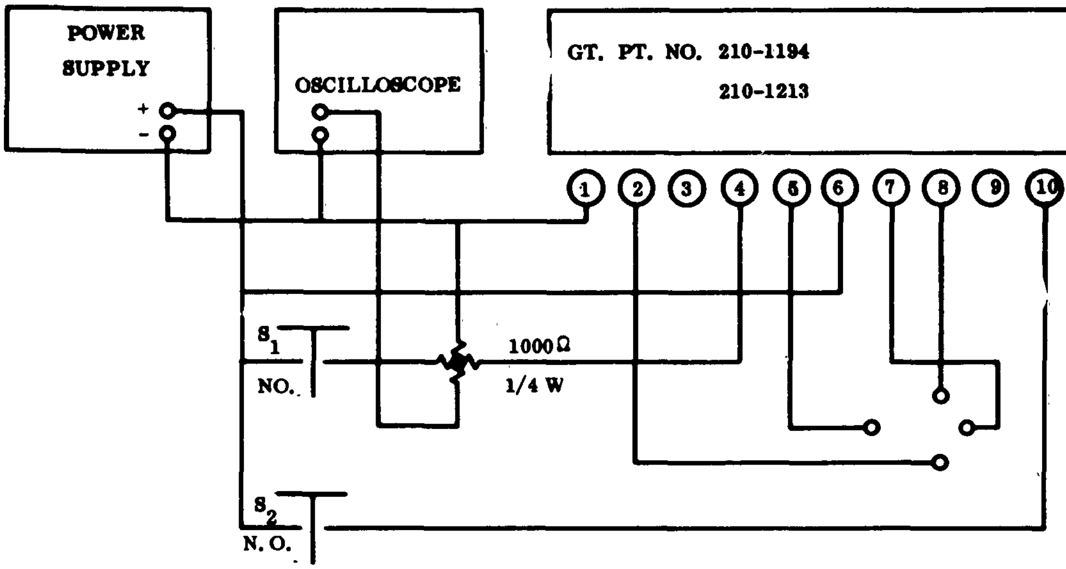


Figure 16. Purge Counter Module Interconnection Diagram
(Circled Numerals Indicate Module Terminal Numbers)

2.0 Variable output.

2.1 Adjust power supply output to 11 volts.

2.2 S_3 is set to the desired division ÷ 4, ÷ 6, ÷ 8.

3.0 Oscilloscope.

3.1 Horizontal sweep - 5 μ sec./cm

3.2 Vertical displacement - 2 volts/cm

3.3 Triggering mode - Positive

3.4 Triggering level - Slightly negative

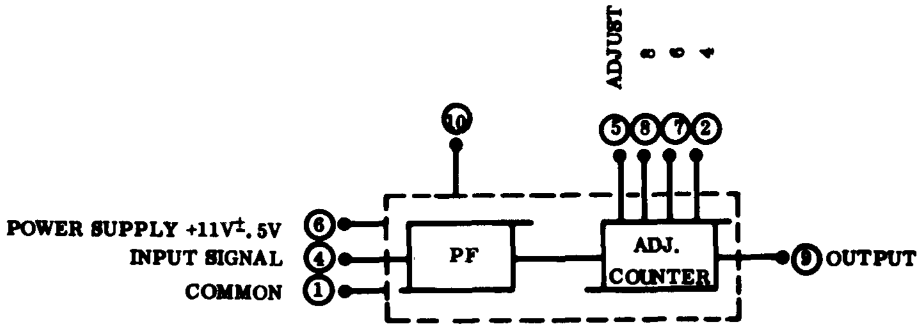
3.5 Place the scope input to terminal 9 of the module.

4.0 Operation.

4.1 With each depression of Switch 1 a pulse will be introduced into the module. If the divider is set to divide by four, four depressions will produce a positive output pulse of 4 ±1 volts of 8 ±1 μ sec. duration. The intermediate negative pulses observed on the scope are "count" pulses. For a divide by four operation three such pulses will be seen, the fourth being the positive output pulse.

4.2 Reset.

4.2.1 If the divider is in a divide by four condition, insert as many pulses needed to obtain an output pulse. Then insert three more. Depress the reset switch S_2 and release instantaneously. Depression of the purge input (S_1) four times should deliver the desired output pulse.



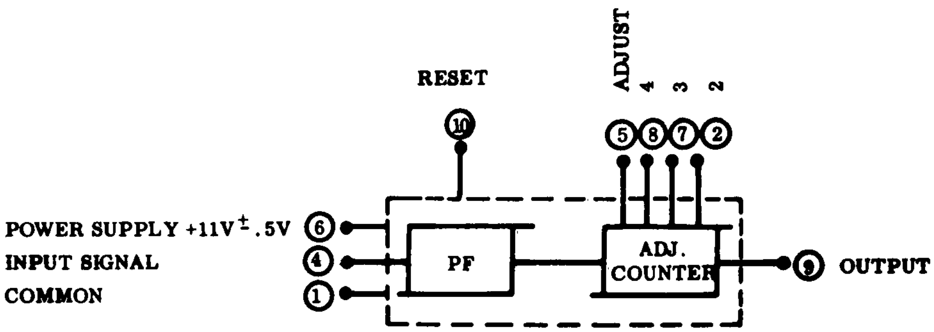
LOGIC DIAGRAM

NOTES:

1) ADJUST DIVISION FACTOR BY:
   DIVIDE 4/1, BUSS, PIN NO's. 5 & 2
   DIVIDE 6/1, BUSS, PIN NO's. 5 & 7
   DIVIDE 8/1, BUSS, PIN NO's. 5 & 8
2) UNIT INPUT IMPEDANCE 270 ± 10% OHMS
3) NUMERALS IN CIRCLE INDICATE HEADER PIN NO.

PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	÷4 TAP	SEE NOTE 1
3	NOT USED	
4	INPUT SIGNAL 10 CPS MAX	4 ± 1V, 3μSEC MIN. LOADED
5	DIVISION FACTOR ADJUST	SEE NOTE 1
6	POWER SUPPLY +11±0.5V	
7	÷6 TAP	SEE NOTE 1
8	÷8 TAP	SEE NOTE 1
9	OUTPUT	8 ± 1μ SEC, 4 ±1V
10	RESET 10 TO 24 VOLTS	50μ SEC TO 0.5 SEC

Figure 17. Specification Divider-Adjustable 4:1, 6:1, 8:1. Module #210-1194



LOGIC DIAGRAM

NOTES:
1) ADJUST DIVISION FACTOR BY:
DIVIDE 2/1, BUSS, PIN NO's. 5 & 2
DIVIDE 3/1, BUSS, PIN NO's. 5 & 7
DIVIDE 4/1, BUSS, PIN No's. 5 & 8
2) UNIT INPUT IMPEDANCE 270 ± 10% OHMS
3) NUMERALS IN CIRCLE INDICATE HEADER PIN NO.

PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	÷ 2 TAP	SEE NOTE 1
3	NOT USED	
4	INPUT SIGNAL 10 CPS MAX	4 ± 1V, 3 μSEC MIN. LOADED
5	DIVISION FACTOR ADJUST	SEE NOTE 1
6	POWER SUPPLY +11 ± 0.5V	
7	÷ 3 TAP	SEE NOTE 1
8	÷ 4 TAP	SEE NOTE 1
9	OUTPUT	8 ± 1μSEC. 4 ± 1V
10	RESET 10 TO 24 VOLTS	50 μSEC TO 0.5 SEC.

Figure 18. Specification Divider-Adjustable 2:1, 3:1, 4:1, Module #210-1213

5.0 GT Part No. 210-1213.

The testing procedure for GT Part No. 210-1213 is as for 210-1194. The difference being that the variable divider will divide by 2, by 3, by 4, instead of by 4, by 6, by 8 as in GT Part No. 210-1194.

DRIVER MODULE PART # 210-1195

Test Procedure

NOTE: Insure power is not applied to unit during the interconnection stage.

1.0 Driver Module Part No. 210-1195.

1.1 Interconnect module as shown in Figure 19

1.2 Terminal description: (See Figure 20 for complete module terminal description list and module specification.)

Terminal 1 - Common
Terminal 2 - +20 volts
Terminal 4 - Inhibit input
Terminal 5 - SCR input
Terminal 8 - Output
Terminal 10 - Reset

2.0 Operation.

2.1 Place S_2 in the off position.

2.2 Pulse generator.

2.2.1 Frequency - 1 cps

2.2.2 Pulse width - 8 μ sec.

2.2.3 Amplitude - +6 volts

2.3 Oscilloscope.

2.3.1 Horizontal sweep - .5 msec./cm

2.3.2 Vertical displacement - 5 volts/cm

2.3.3 Triggering mode - Positive

2.3.4 Triggering level - Positive

2.3.5 Place scope input to terminal 10 on the module.

2.4 Slowly apply 20 volts to terminal 2. Wait thirty seconds.

2.5 Place S_2 such that the pulse generator is connected to terminal 4. A positive pulse, exponential in nature, of approximately 10 volts in amplitude and of approximately one millisecond in duration should appear. Before repeating this test, the signal must be removed from terminal 4 and a period of 30 seconds must elapse from that time.

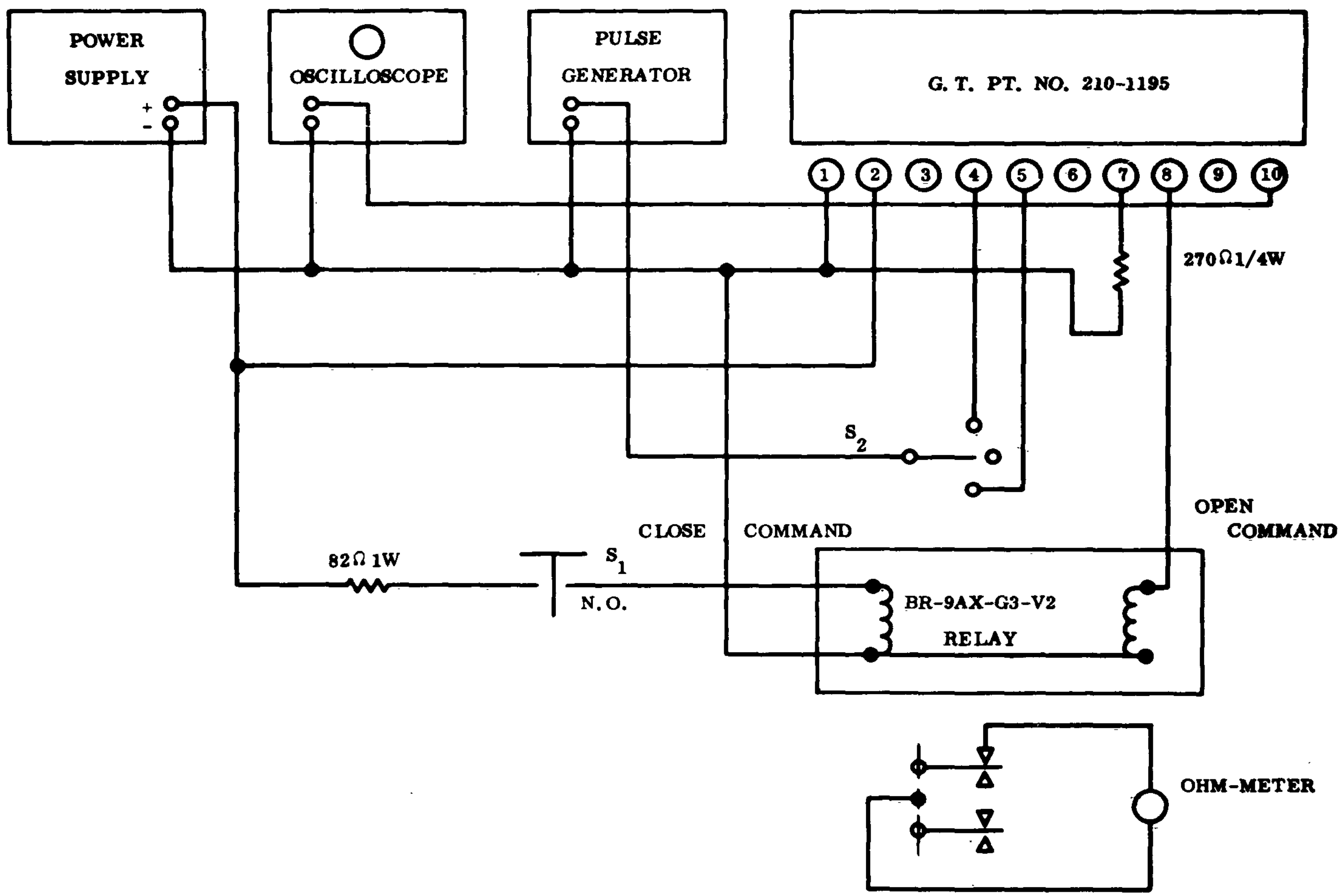
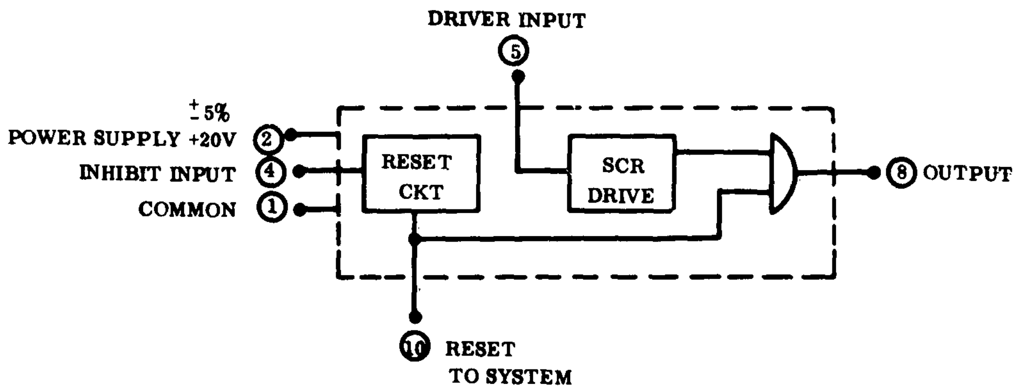


Figure 19. Driver Module Interconnection Diagram. (Circled Numerals Indicate Module Terminal Numbers.)



NOTE:
NUMERALS IN CIRCLE INDICATE
HEADER PIN NO.

PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	POWER SUPPLY +20V ± 5%	
3	NOT USED	
4	INHIBIT INPUT 3 TO 10 VOLTS	5 μ SEC. TO 0.5 SEC.
5	DRIVER INPUT 5 ± 2 VOLTS	5 μ SEC. TO 0.5 SEC.
6	NOT USED	
7	NOT USED	
8	OUTPUT	RELAY DRIVE
9	NOT USED	
10	RESET TO SYSTEM OUTPUT	100 μ SEC.

Figure 20. Specification Purge Drive & Reset Module #210-1195

3.0 SCR Drive Circuit.

3.1 Place S_2 in the off position.

3.2 Depress S_1 and note that the contacts of the relay are closed.

3.3 Place S_2 such that the pulse generator is connected to terminal 5. Note that the relay contacts are open.

4.0 Inhibit.

4.1 Place S_2 in the off position.

4.2 Depress S_1 and note that the relay contacts are closed. Wait 30 seconds.

4.3 Place S_2 such that the pulse generator is connected to terminal 4. Quickly place S_2 such that the pulse generator is now connected to terminal 5. The relay contacts shall remain closed. The SCR Drive Circuit shall be inhibited.

4:1 DIVIDER MODULE PART # 210-1196

Test Procedure

NOTE: Insure power is not applied to unit during the interconnection stage.
1

1.0 4:1 Divider Module Part No. GT 210-1196.

1.1 Interconnect as shown in Figure 21.

1.2 Terminal description: See Figure 22 for complete module terminal description list and module specification.

Terminal 1 - Common
Terminal 2 - +20 volts
Terminal 3 - SCR anode (CAP)
Terminal 4 - Signal input
Terminal 5 - SCR input
Terminal 6 - +11 volts
Terminal 7 - Divide by four output
Terminal 8 - Babcock relay "close command"
Terminal 9 - Divide by two output
Terminal 10 - Reset

2.0 Divide by 2 output.

2.1 Adjust power supply one output to 11 volts.

2.2 Pulse generator.

2.2.1 Frequency - 200 cps
Pulse width - 8 μ sec.
Loaded amplitude - +4 volts

2.3 Oscilloscope.

2.3.1 Horizontal sweep - .1 msec/cm

2.3.2 Vertical displacement - 2 volts/cm

2.3.3 Triggering mode - Positive

2.3.4 Triggering level - Positive

2.3.5 Place the scope input to terminal 9 of the divider module. A 100 pps output (pulse every 10 msec.) shall appear. It will be positive going at 4 ±1 volt and 8 ±1 μ sec. The smaller negative pulse is the count pulse and should be observed. To determine the character of the output pulse after the frequency has been verified, decrease the horizontal sweep to 2 μ sec./cm and verify that output is 4 ±1 volt at 8 ±1 μ sec.

3.0 Divide by 4 output.

3.1 Pulse generator.

3.1.1 Frequency - 400 cps

3.1.2 Pulse width - 8 μ sec.

3.1.3 Loaded amplitude - +4 volts

3.2 Oscilloscope.

3.2.1 As in Paragraph 2.3.1 - 2.3.4

3.2.2 Place the scope input to terminal 7. Refer to Paragraph 2.3.5.

4.0 Reset.

4.1 Pulse generator.

4.1.1 Frequency - 2 cps

4.1.2 Pulse width - 8 μ sec.

4.1.3 Loaded amplitude - +4 volts

4.2 Oscilloscope.

4.2.1 Horizontal sweep - 5 μ sec./cm

4.2.2 Vertical displacement - 2 volts/cm

4.2.3 Triggering mode - Positive

4.2.4 Triggering level - Slightly negative

4.2.5 Place the scope input to terminal 7 of the divider module. At the termination of an output pulse (+4 volts at 8 μ sec.) a negative pulse of approximately 1 volt at 6-7 μ sec. duration will appear one second later. The negative pulse is the "one count" pulse and the positive output pulse the "two count" pulse. Count out a complete cycle of two, that is one negative and one positive output pulse. At the following negative pulse, disconnect the signal input to the module with the use of S_3. Depress the Reset switch S_1 and release instantaneously. Reconnect the signal input to the module. An immediate count of two must be observed to verify reset.

5.0 SCR Drive circuit.

5.1 Adjust power supply II output to 20 volts.

5.2 Depress Relay Switch S_2 to insure transference of relay contacts to an open position.

5.3 Pulse generator

NOTE: 2 A time interval of at least 30 seconds is required after the SCR drive circuit is actuated before actuating the circuit again.

5.3.1 Frequency - 1 cps

5.3.2 Pulse width - 8μ sec.

5.3.3 Loaded amplitude - +4 volts

6.0 Operation.

6.1 Depress Relay Switch (switch 2). Ohmmeter shall read open.

6.2 Apply signal to module input. In approximately four seconds the contacts shall transfer and the ohmmeters will read "closed."

6.3 Depress relay switch - see "NOTE 2."

6.4 Apply signal to terminal 5. The relay contacts should transfer instantaneously the ohmmeter reading of "open" to "closed."

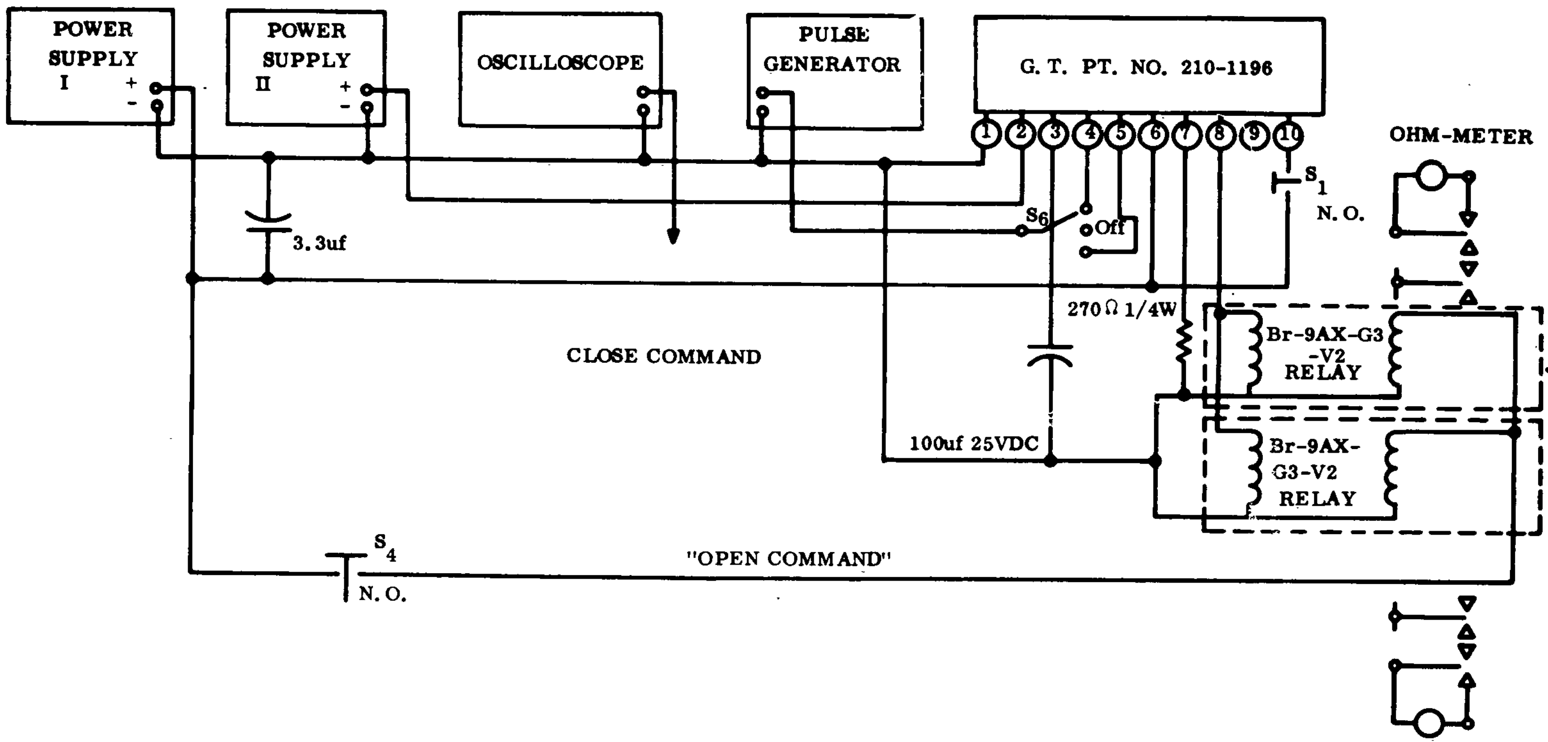
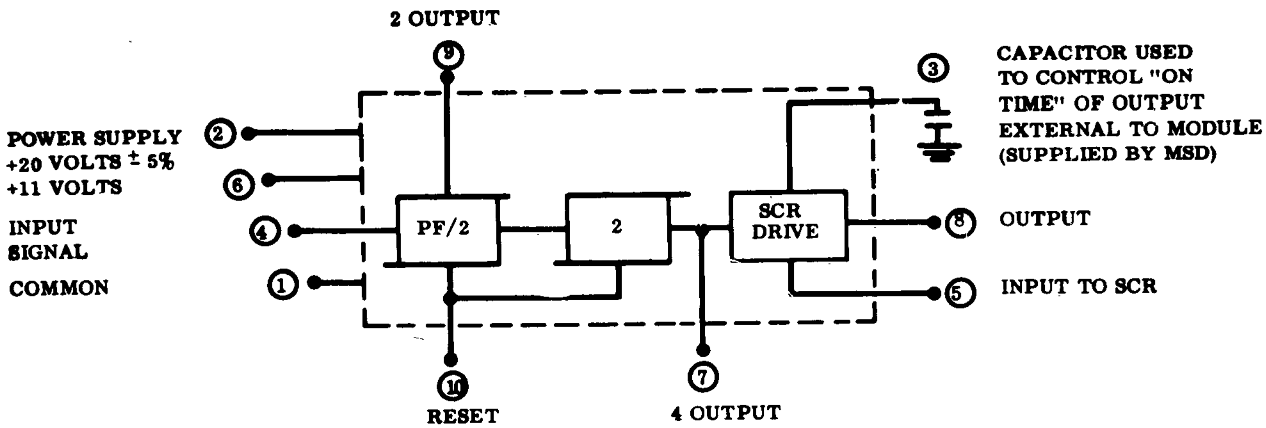


Figure 21. 4:1 Divider Module Interconnection Diagram. (Circled Numerals Indicate Module Terminal Numbers.)



NOTES:

1. UNIT INPUT IMPEDANCE 270± 10% OHMS
2. NUMERALS IN CIRCLE IND. GATE HEADER PIN NO.

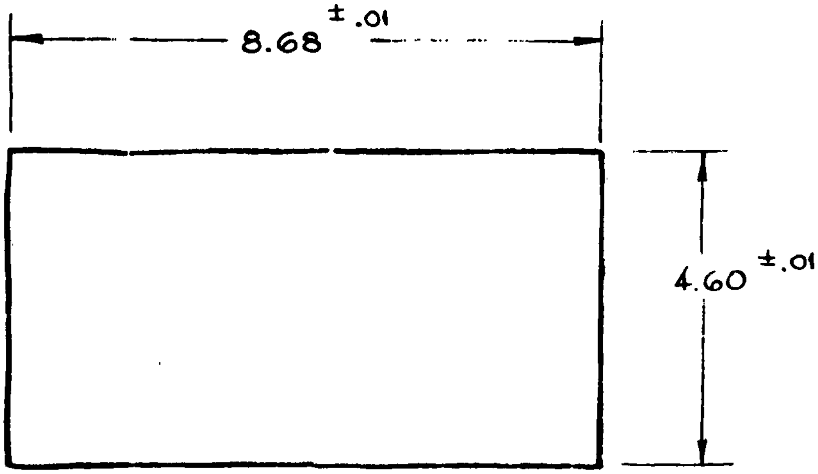
PIN NO.	FUNCTION	REMARKS
1	COMMON	
2	POWER SUPPLY 20 VOLTS ± 5%	
3	OUTPUT CONTROL	SCR ANODE
4	INPUT SIGNAL 20KC MAX.	8±1 μSEC. 4 ± 1 VOLT WHEN LOADED
5	INPUT TO SCR	5 μSEC. TO .5 SEC. 3 TO 10 VOLTS
6	REGULATED POWER +11±.5 VOLTS	
7	÷ 4 OUTPUT	8 μSEC. 4 VOLTS
8	OUTPUT	RELAY DRIVE
9	÷ 2 OUTPUT	8 μSEC. 4 VOLTS
10	RESET 10 TO 24 VOLTS	50 μSEC. TO 0.5 SEC.

Figure 22. Specification Divider 4:1 Drive Module #210-1196

APPENDIX 2-D

DETAILED PRODUCT

DESIGN DRAWINGS

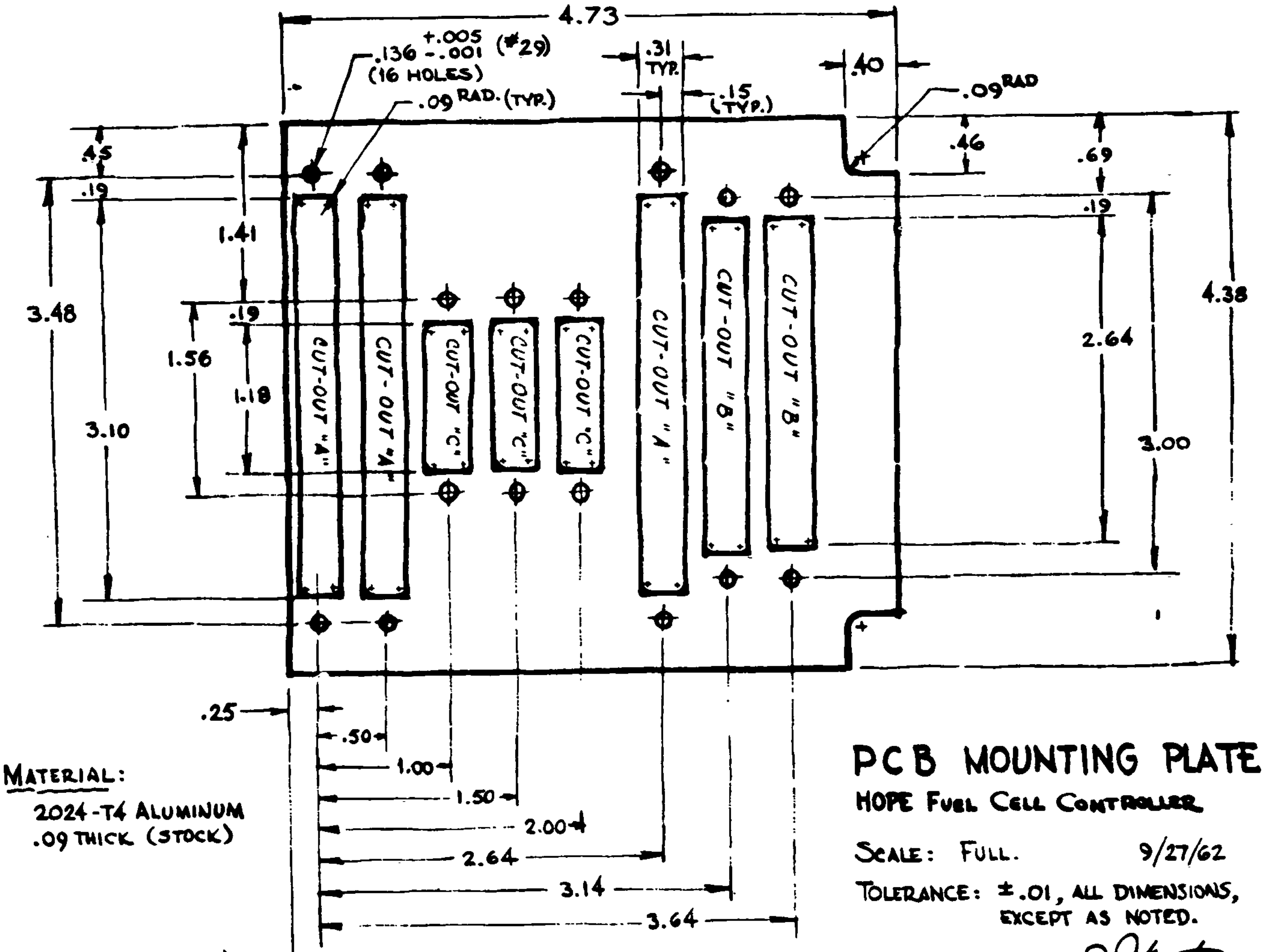


MATERIAL: 2024-T4 ALUMINUM
.06 THICK (STOCK)

SIDE PANEL NO. 2

HOPE FUEL CELL CONTROLLER

SCALE: 1/2 9/26/62



MATERIAL:
2024-T4 ALUMINUM
.09 THICK (STOCK)

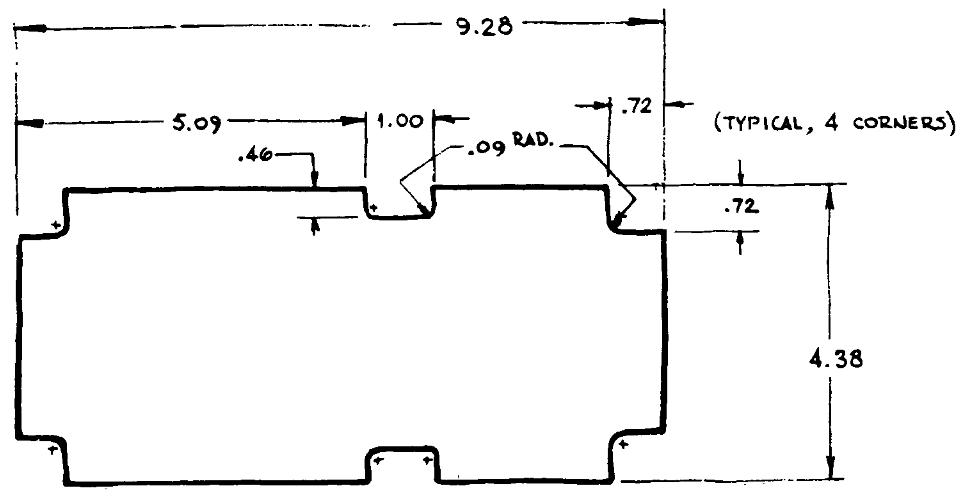
(Ref. SK56122-595P14)

PCB MOUNTING PLATE

HOPE FUEL CELL CONTROLLER

SCALE: FULL. 9/27/62

TOLERANCE: ±.01, ALL DIMENSIONS, EXCEPT AS NOTED.



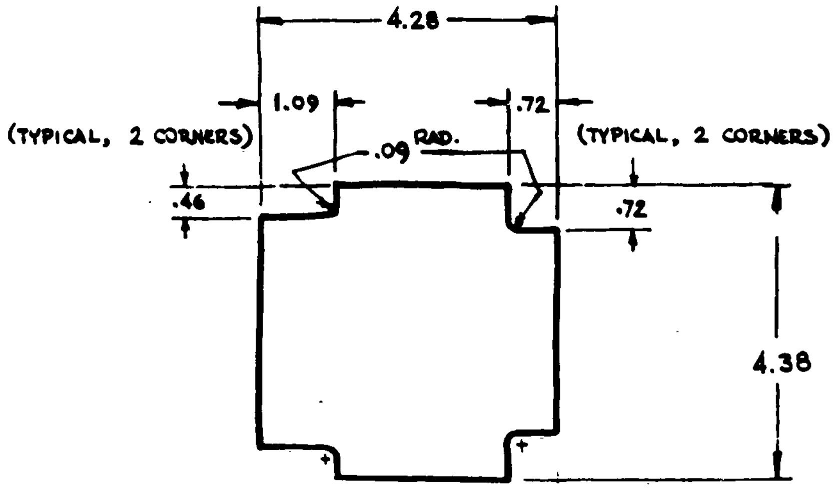
MATERIAL: 2024-T4 ALUMINUM
.09 THICK (STOCK)

TIMER MOUNTING PLATE
HOPE FUEL CELL CONTROLLER

SCALE: 1/2. 9/27/62

TOLERANCE: ±.01, ALL DIMENSIONS.

(REF. SK56122-595P9)



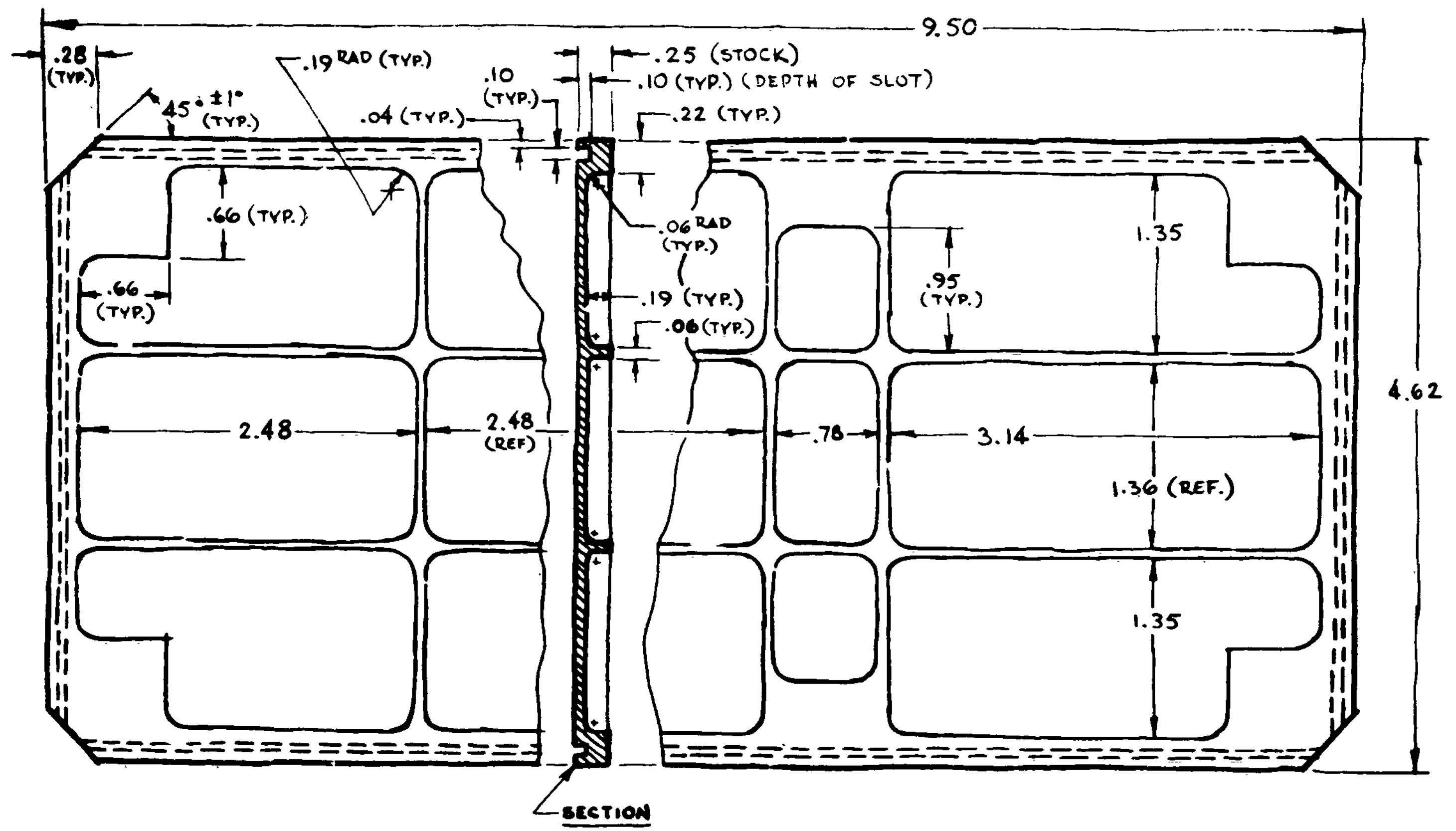
MATERIAL: 2024-T4 ALUMINUM
.09 THICK (STOCK)

SCR MOUNTING PLATE
HOPE FUEL CELL CONTROLLER

SCALE: 1/2. 9/27/62

TOLERANCE: ±.01, ALL DIMENSIONS.

(REF. SK56122-595P12)



MATERIAL: 2024-T3 (OR -T4) ALUMINUM
.25 THICK (STOCK)

COVER PLATE

HOPE FUEL CELL CONTROLLER

SCALE: FULL 10/5/62

TOLERANCE: ±.01 FOR ALL LINEAR DIMENSIONS.

SK92262

NOTES

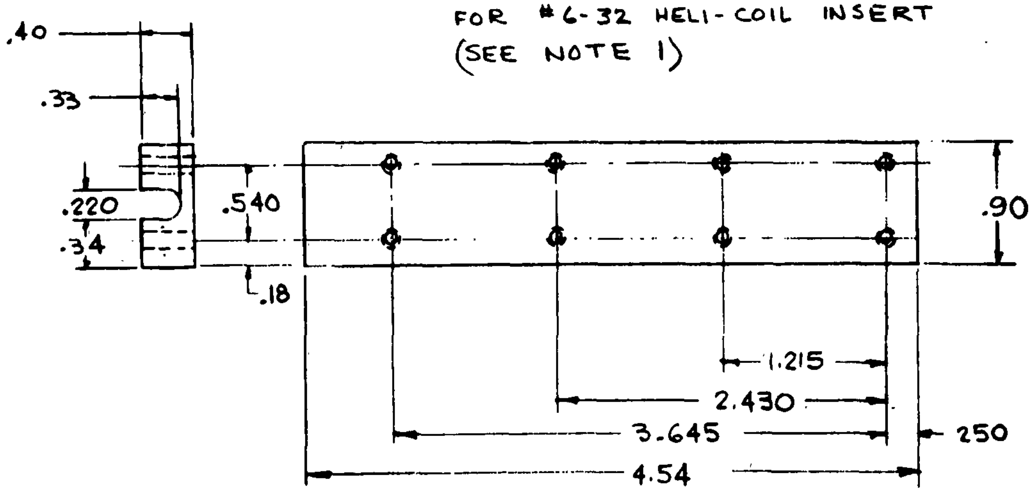
1. DRILL SIZE IS STANDARD
   TAP SIZE IS SPECIAL

2 DWG TERMS & TOLERANCES
   PER 118A1664

TOLERANCES	.XX ± .01
	.XXX ± .005

MATL QQ-A-268 - 2024-T4

ALL HOLES DRILL & TAP
FOR #6-32 HELI-COIL INSERT
(SEE NOTE 1)



SK92262

SK92162

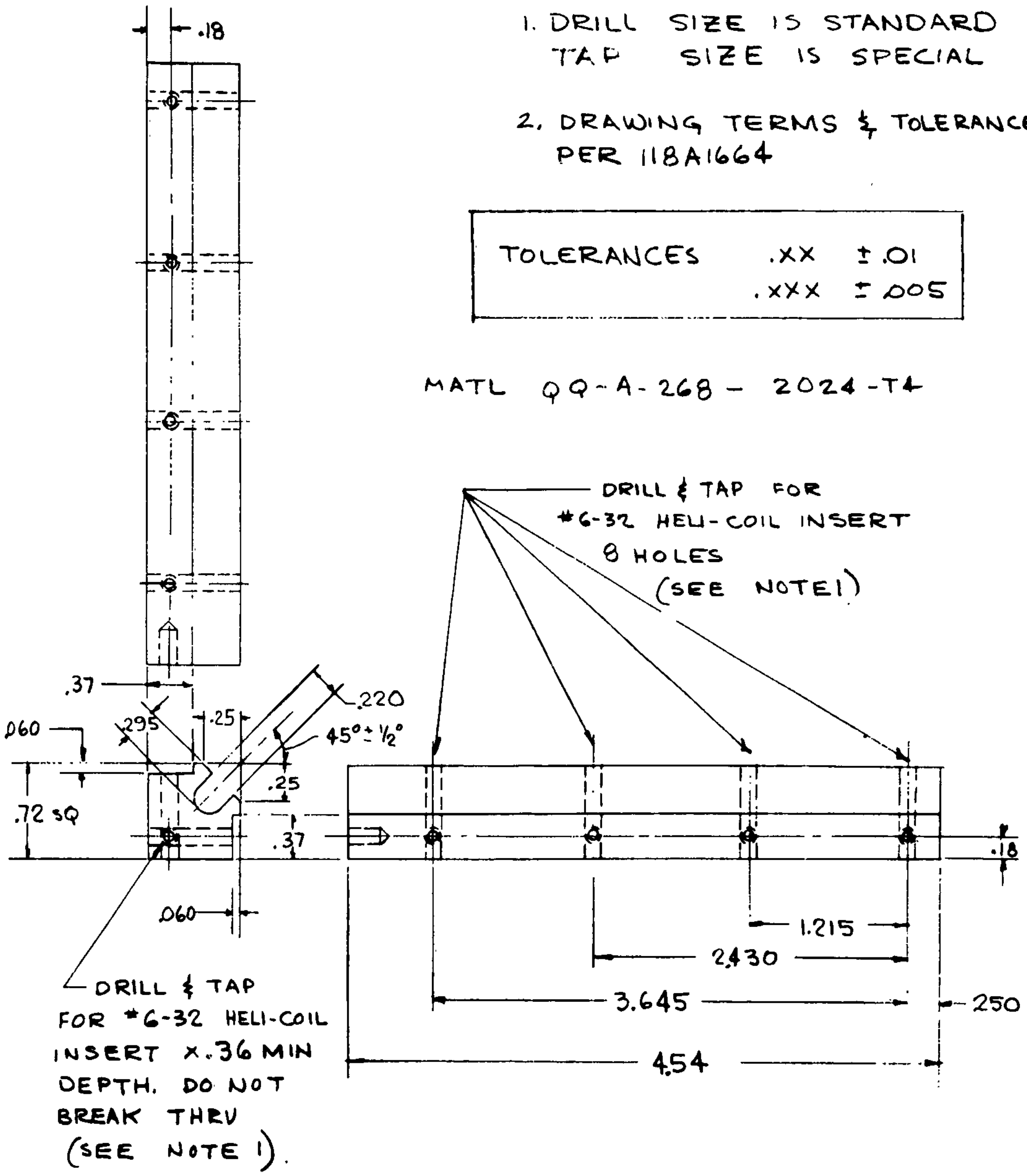
NOTES

1. DRILL SIZE IS STANDARD
   TAP SIZE IS SPECIAL

2. DRAWING TERMS & TOLERANCES
   PER 118A1664

TOLERANCES	.XX	± .01
	.XXX	± .005

MATL QQ-A-268 - 2024-T4



SK92162

BY NF GRANT	GENERAL ELECTRIC	PAGE 1 OF 1
CK.	SPACECRAFT DEPARTMENT	MODEL DTV FCC
DATE 1[illegible]-62 REV. A	VF STC	REPORT HOPE

HELI-COIL INSERT INFORMATION* FOR HOPE DTV FCC

1. INSERT IDENTIFICATION.

NAS No.	HELI-COIL No.	ITEM	QTY/FCC
1222-06E	3585-06CN 0276	INSERT, SCREW THREAD, HELICAL COIL, SCREW LOCKING, #6-32 x .276 LONG	44

2. TOOLS.

   a. No. 25 TWIST DRILL.
   b. 120° COUNTERSINK.
   c. 06CPA HELI-COIL PLUG TAP.
   d. 7551-06 HELI-COIL INSTALLATION TOOL.
   e. 3580-06 HELI-COIL TANG BREAK-OFF TOOL.
   f. 1227-06 HELI-COIL EXTRACTING TOOL.

3. OPERATIONS.

   a. DRILL $\frac{.150}{.144}$ DIA. HOLE (#25 DRILL), .488 (MIN.) DEEP.

   b. COUNTERSINK (120°) TO $\frac{.20}{.17}$ DIA.

   c. TAP .310 (MIN.) DEEP.

   d. INSTALL INSERT. OUTER COIL TO BE $\frac{.047}{.023}$ BELOW SURFACE.

   e. BREAK OFF TANG.

* FROM HELI-COIL BULLETIN 800, DATED 1962.

FORM 1-8136 A (9-58)

PARTS REQUIRED TO MAKE (1) FUEL CELL CONTROLLER. (STRUCTURE ONLY)

NAME	DWG.	QTY
SIDE PLATE	SK56122-595	1
SIDE PLATE		1
END PLATE		1
END PLATE		1
COMPONENT PLATE		1
COMPONENT PLATE		1
RELAY PLATE	SK56122-595	1
CONNECTOR	CANNON DDM-50P	2
CORNER POST	SK92162	4
MIDSECTION SUPPORT	SK92262	2
HELI-COIL INSERTS (NAS 1222-06)	# 6-32 (1½ DIA) .207 LONG	52
#6-32 SCREW	MS35216-24	48
#6-32 SCREW	MS35216-23	26
#6-32 SELF LOCKING	NAS 1291-C06	36
PRINTED CIRCUIT CONN	14P	3
PRINTED CIRCUIT CONN.	31P	2
PRINTED CIRCUIT CONN	37P	3
PRINTED BOARD CLIPS		16

#4-40	MS35216-14	20
#4-40 SELF LOCKING NUT	NAS1291-C04	20
INSULATED SPACER	118A1557 P3 5/8 LONG	2
" "	" 1 3/4 LONG	1
" "	118A1557 P3 1 1/8 LONG	1
#6-32 SCREW	MS35216-35	1
"	" -31	2
#6-32 SCREW	MS35216-33	1

BY NF GRANT	GENERAL ELECTRIC SPACECRAFT DEPARTMENT VF STC	PAGE 1 OF 1
CK.		MODEL DTV FCC
DATE 10-15-62 REV. A.		REPORT HOPE

ASSEMBLY HARDWARE - HOPE DTV FUEL CELL CONTROLLER

IDENT. NO.	ITEM	QTY.
MS 24584-16	Screw, mach., pan hd., cross-rec., #4-40 x 1/2 long.	16
-23	Ditto, #6-32 x 1/4 long.	26
-25	Ditto, #6-32 x 3/8 long.	40
-28	Ditto, #6-32 x 5/8 long.	4
-30	Ditto, #6-32 x 7/8 long.	2
-33	Ditto, #6-32 x 1 1/2 long.	1
-35	Ditto, #6-32 x 2 long.	1
D 20418-2	Screw, female lock assembly, Cannon, #4-40 thd.	4
NAS 1291C04	Nut, self-lock., hex., low ht., lt. wt., #4-40.	16
-C06	Ditto, #6-32.	
-C3	Ditto, #10-32.	
118A1684P12	Nut, self-lock., plate - rt. angle, floating, #6-32.	26
NAS 1222-06E	Insert, scr. thd., hel. coil, scr. lock., #6-32 x .276 lg.	44
MS 20470B2-3	Rivet, solid - univ. hd., 1/16 dia. x 3/16 long.	52
-B3-2	Ditto, 3/32 dia. x 1/8 long.	32
118A1566P2A x .51	Spacer, sleeve - metallic, .51 long.	2
x 1.06	Ditto, 1.06 long.	1
x 1.66	Ditto, 1.66 long.	1
158-4	Clip, printed circuit board retaining, Birtcher.	16
MS 35490-19	Grommet, rubber, split, general purpose.	1
NP 206430	Plate, identification.	1

FORM 1-0136 A (8-58)

BY NF GRANT	GENERAL ELECTRIC SPACECRAFT DEPARTMENT VF STC	PAGE 1 OF 1
CK.		MODEL DTV FCC
DATE 10-15-62 REV. A		REPORT HOPE

CONNECTORS - HOPE DTV FUEL CELL CONTROLLER

IDENT. NO.	ITEM	QTY.
KM14S	CONNECTOR, WINCHESTER, 14-PIN.	3
KM31S	DITTO, 31-PIN.	2
KM37S	DITTO, 37-PIN.	3
DD50P-C7	CONNECTOR, CANNON, 50-PIN, MALE.	1
DD50S-C7	DITTO, FEMALE.	1

FORM 1-8136 A (9-58)

BY NF GRANT	GENERAL ELECTRIC	PAGE 1 OF 1
CK.	SPACECRAFT DEPARTMENT VF STC	MODEL DTV FCC
DATE 10-9-62 REV. -		REPORT HOPE

NAMEPLATE MARKINGS FOR HOPE DTV FUEL CELL CONTROLLER

1. Nameplate: NP 206430 Plate, Identification.

2. Nameplate Markings.

a. Nomenclature: CONTROLLER, FUEL CELL

b. Stock Number: [Leave blank in Phase Ia.]

c. Serial Number: [Select from following block:]
DTV-01
DTV-02
DTV-03

d. Model: [Construct from prefix, "GE," + drawing no. + suffix, "G__".]

e. Drawing Number: [Later. May be "SK" series sketch no.]

f. Contract Number: AF 33(616)-8159

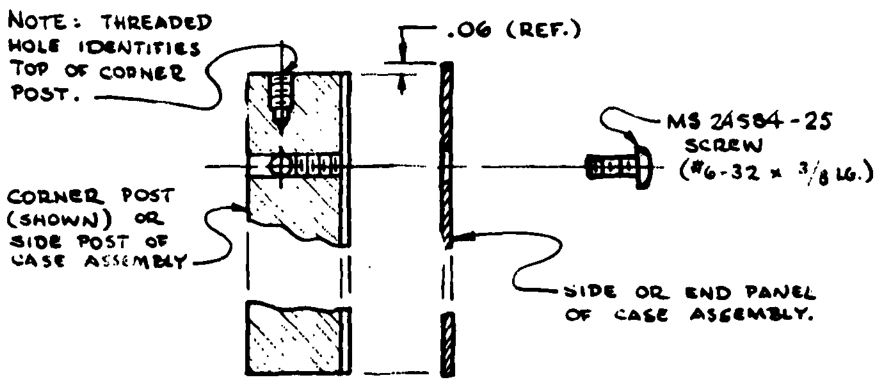
— Information above was received or confirmed in response to PIR No. 9184-041, dated 10-8-62, from NF Grant to R. Luck.

FORM 1-0136 A (9-60)

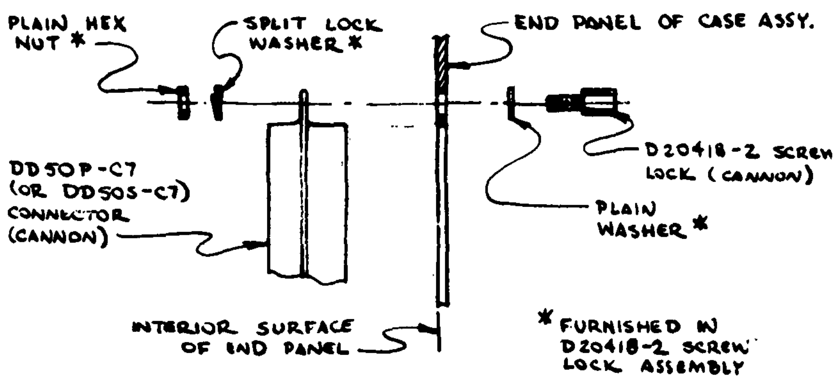
BY NF GRANT	GENERAL ELECTRIC	PAGE 1 OF 4
CK.	SPACECRAFT DEPARTMENT	MODEL DTV FCC
DATE 10-12-62 REV. B	VF STC	REPORT HOPE

ASSEMBLY NOTES FOR HOPE DTV FUEL CELL CONTROLLER

I. Assembly of SIDE PANELS and END PANELS to POSTS.



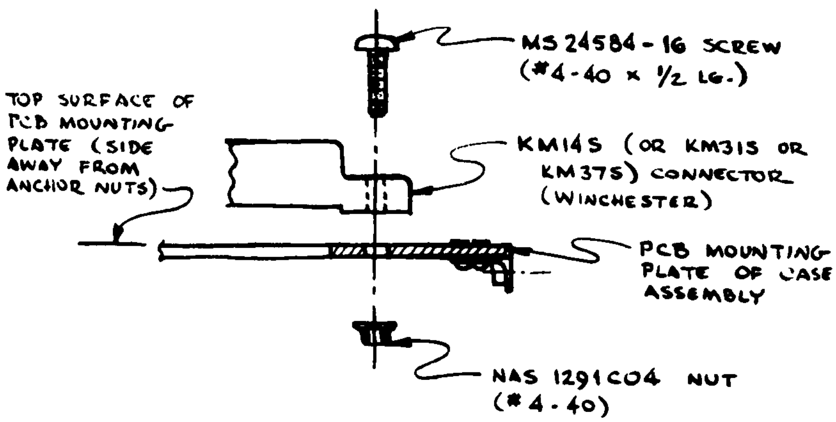
II. Installation of CANNON CONNECTORS.



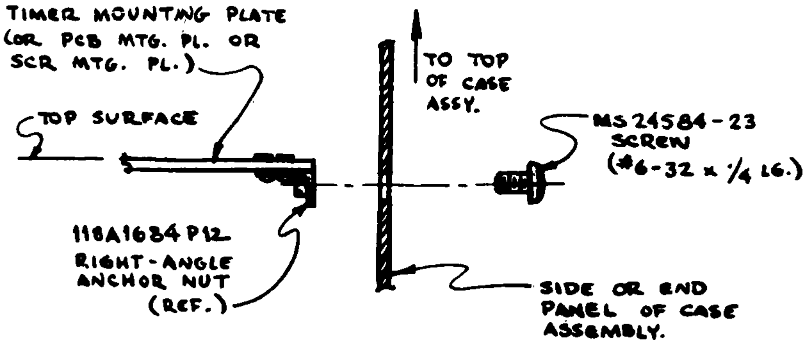
CONT'D ON P. 2

FORM 1-8136 A (9-58)

III. INSTALLATION OF WINCHESTER CONNECTORS.



IV. INSTALLATION OF MOUNTING PLATES IN CASE ASSEMBLY.

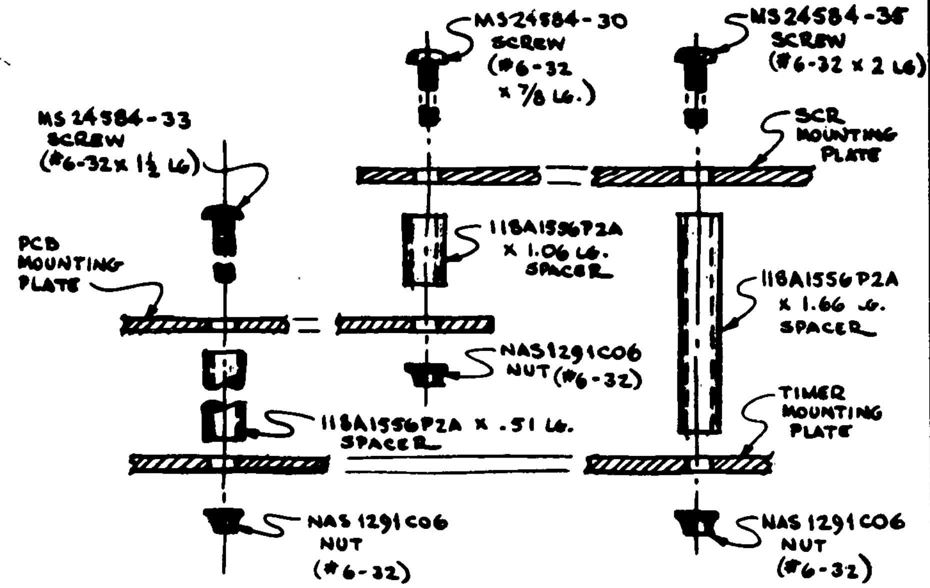


CONT'D ON P. 3

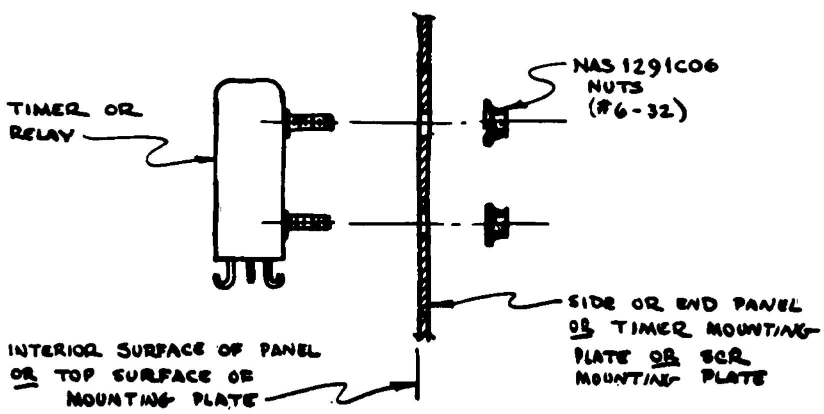
BY NF GRANT CK. DATE 10-12-62 REV. B	GENERAL ELECTRIC SPACECRAFT DEPARTMENT VF STC	PAGE 3 of 4 MODEL DTV FCC REPORT HOPE

(FCC ASSEMBLY NOTES, CONT'D.)

V. INSTALLATION OF SPACERS BETWEEN MOUNTING PLATES.



VI. INSTALLATION OF TIMERS AND RELAYS.

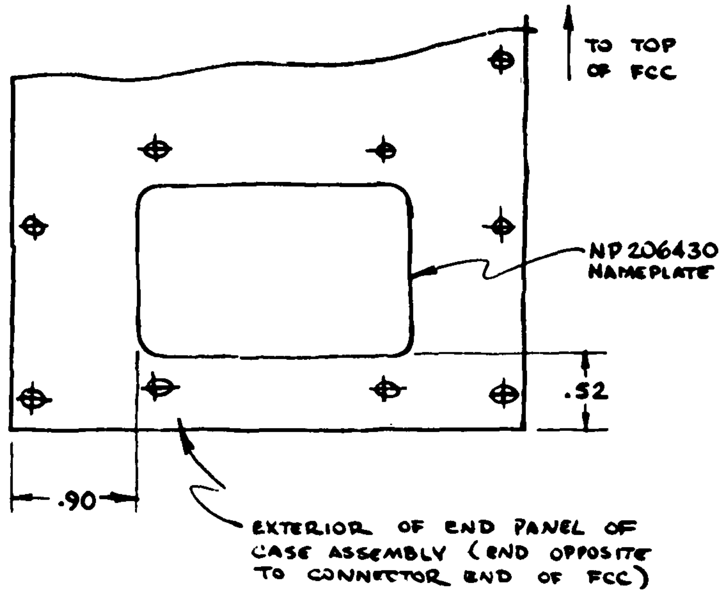


FORM 1-0156 A (9-60)

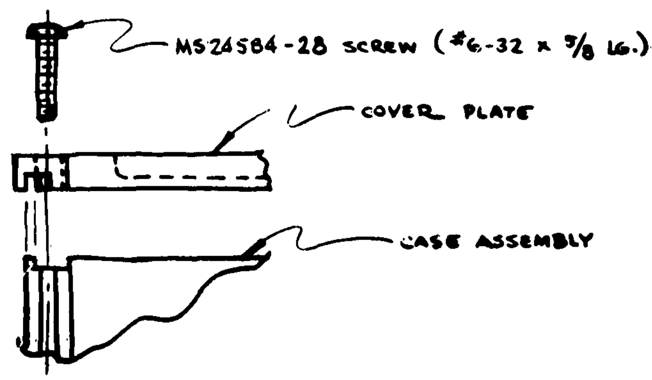
BY VF GRANT	GENERAL ELECTRIC	PAGE 4 OF 4
CK.	SPACECRAFT DEPARTMENT	MODEL DTV FCC
DATE 10-12-62 REV. B	VF STC	REPORT HOPE

(FCC ASSEMBLY NOTES, CONT'D.)

VII. ASSEMBLY OF NAMEPLATE TO CASE.

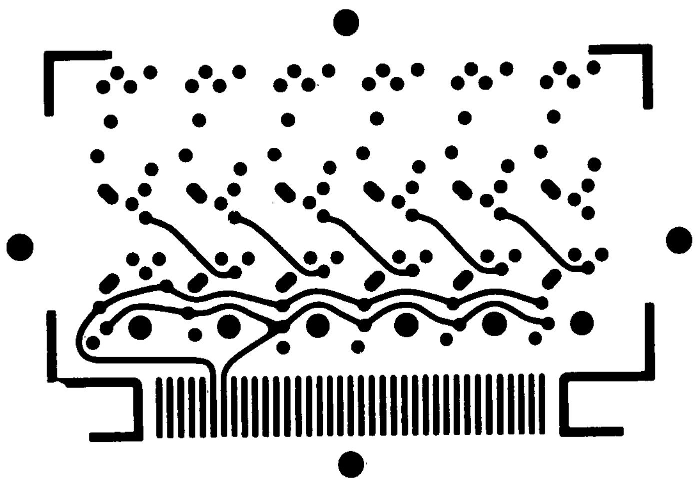


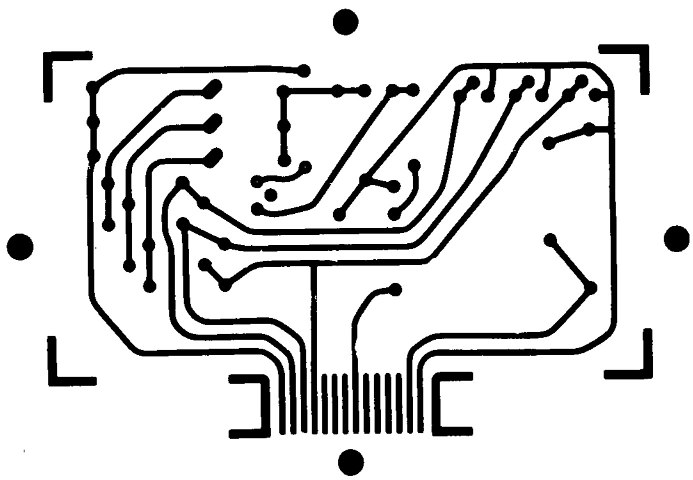
VIII. ASSEMBLY OF COVER PLATE TO CASE.

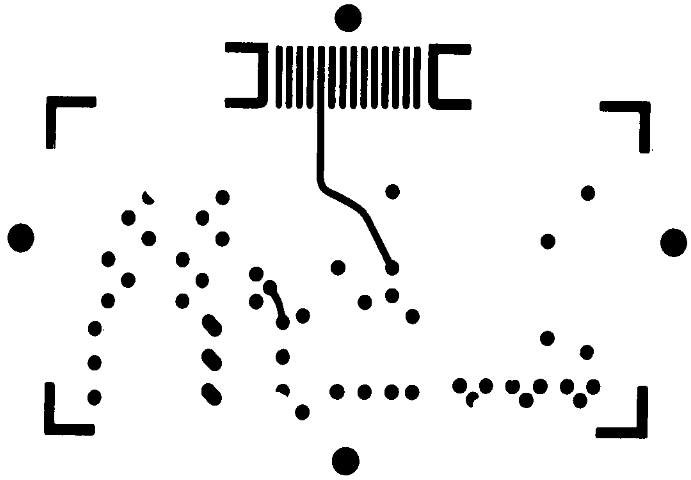


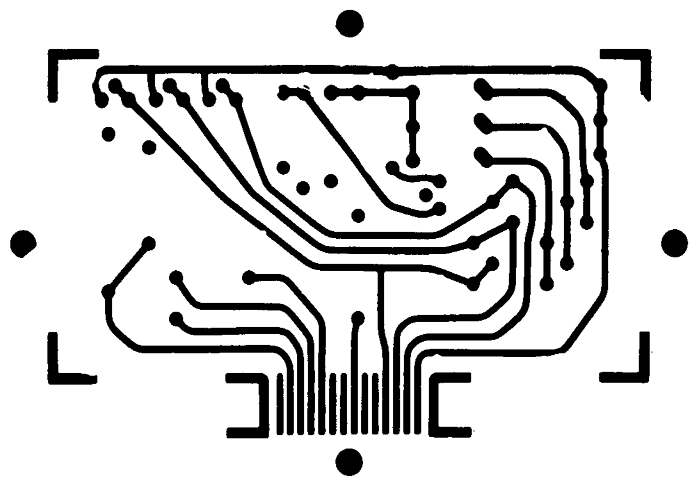
FINAL

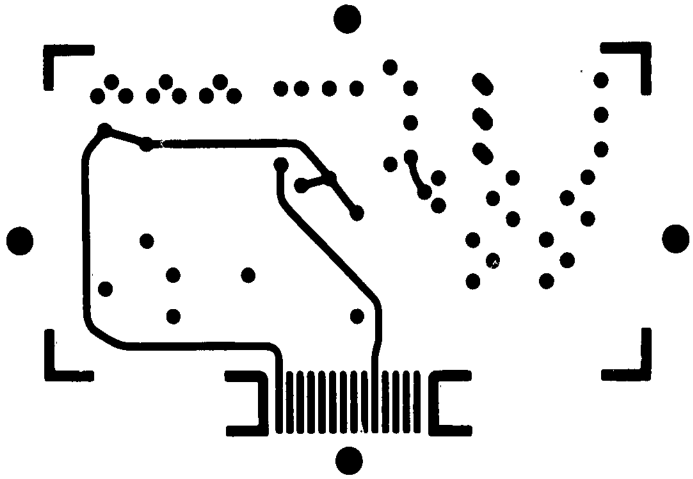
FORM 1-0138 A (9-60)

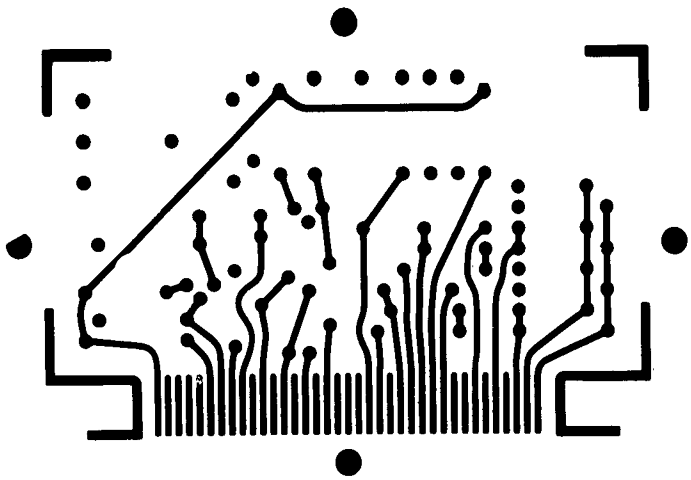


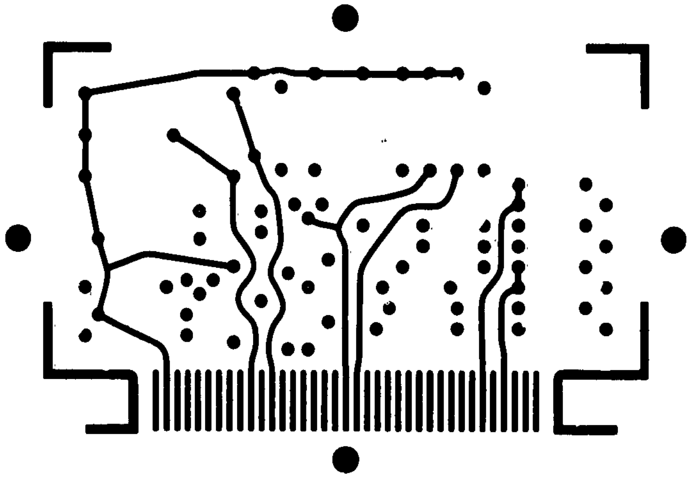


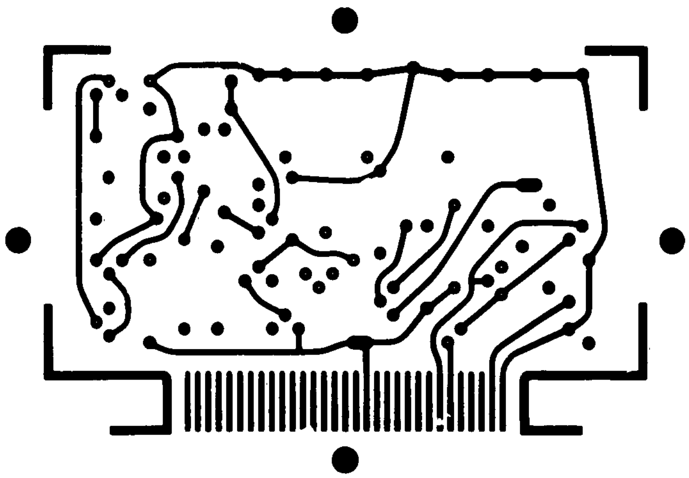


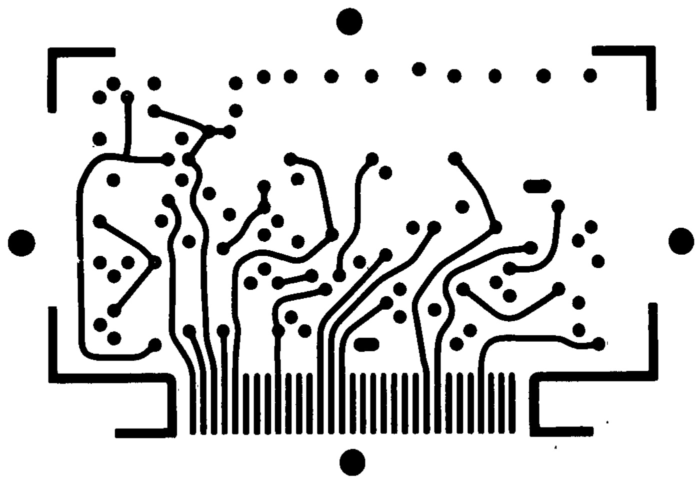


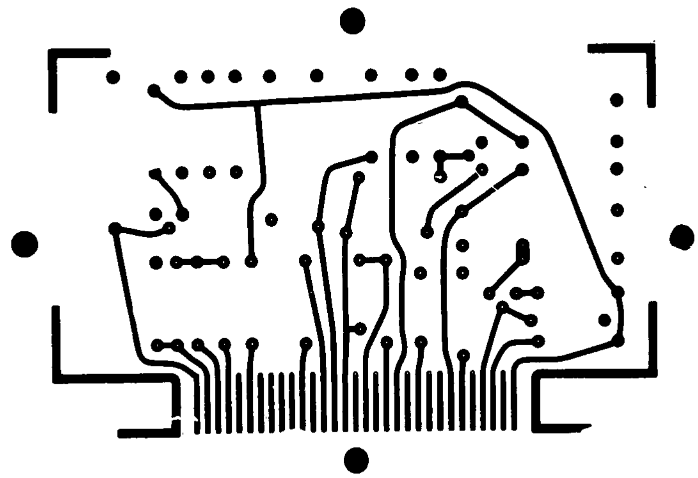


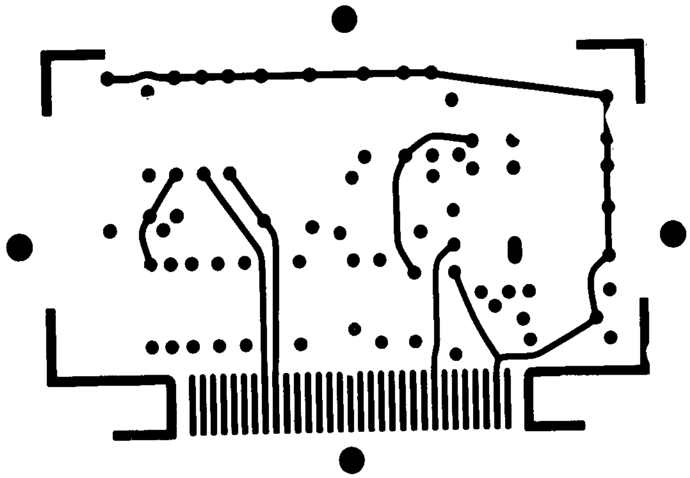


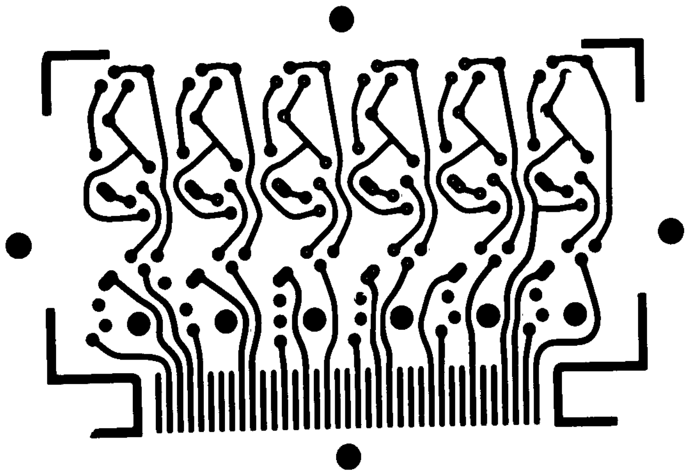


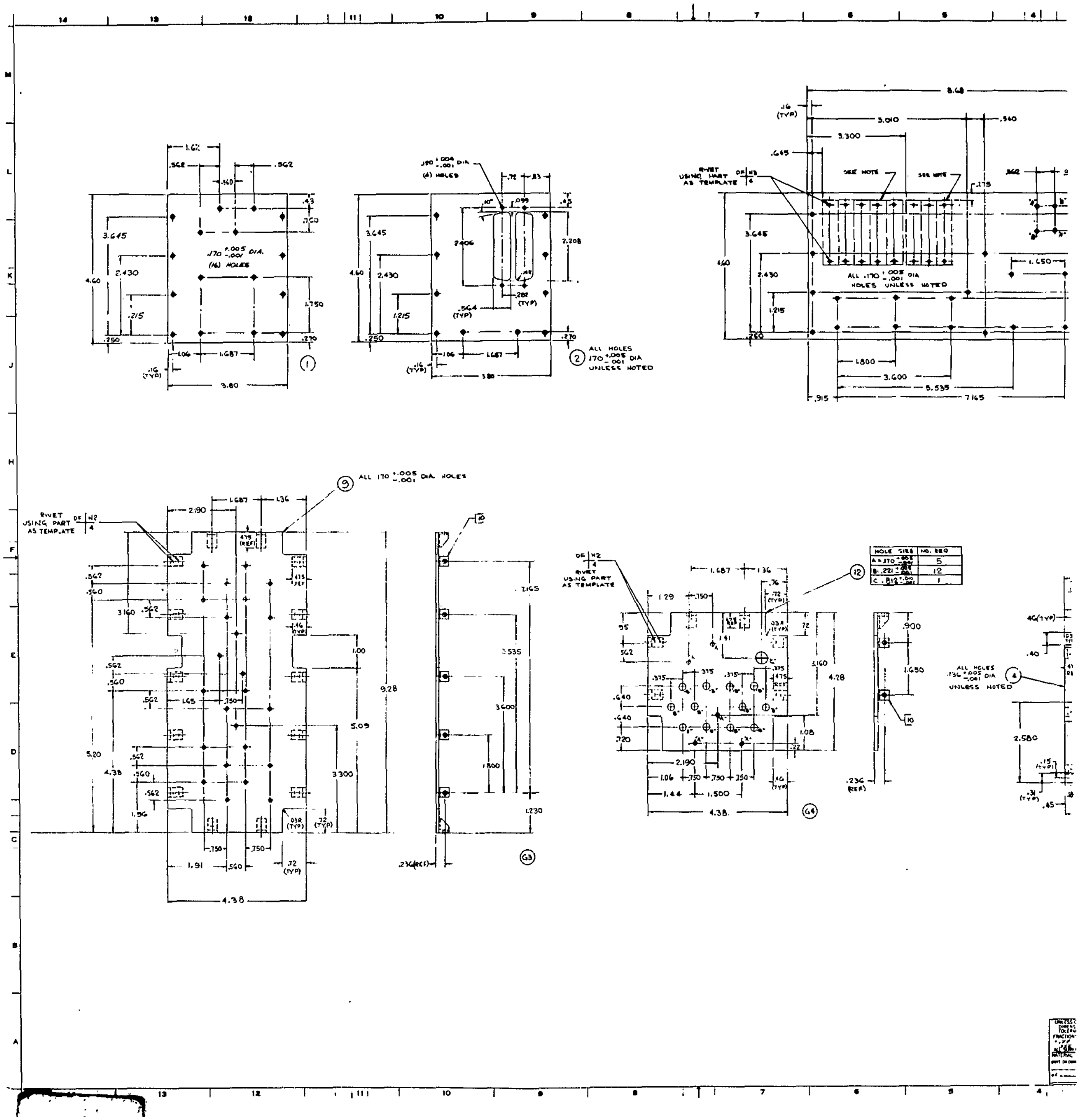






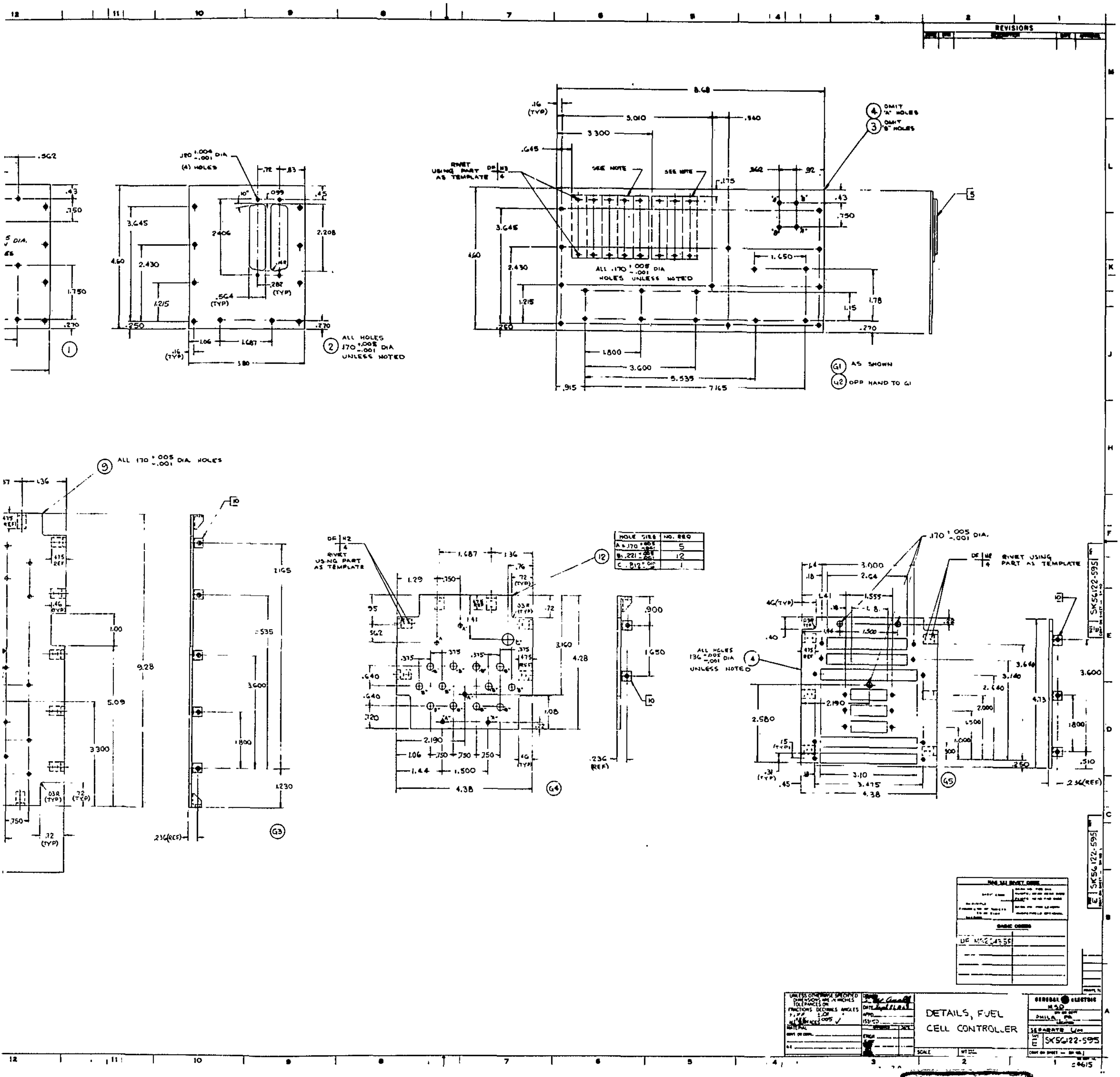






.170 +.005 -.001 DIA. (16) HOLES
ALL HOLES .170 +.005 -.001 DIA UNLESS NOTED
ALL .170 +.005 -.001 DIA HOLES UNLESS NOTED
RIVET USING PART AS TEMPLATE
SEE NOTE
ALL .170 +.005 -.001 DIA. HOLES
HOLE SIZE
NO. REQ
ALL HOLES .136 +.005 -.001 DIA UNLESS NOTED

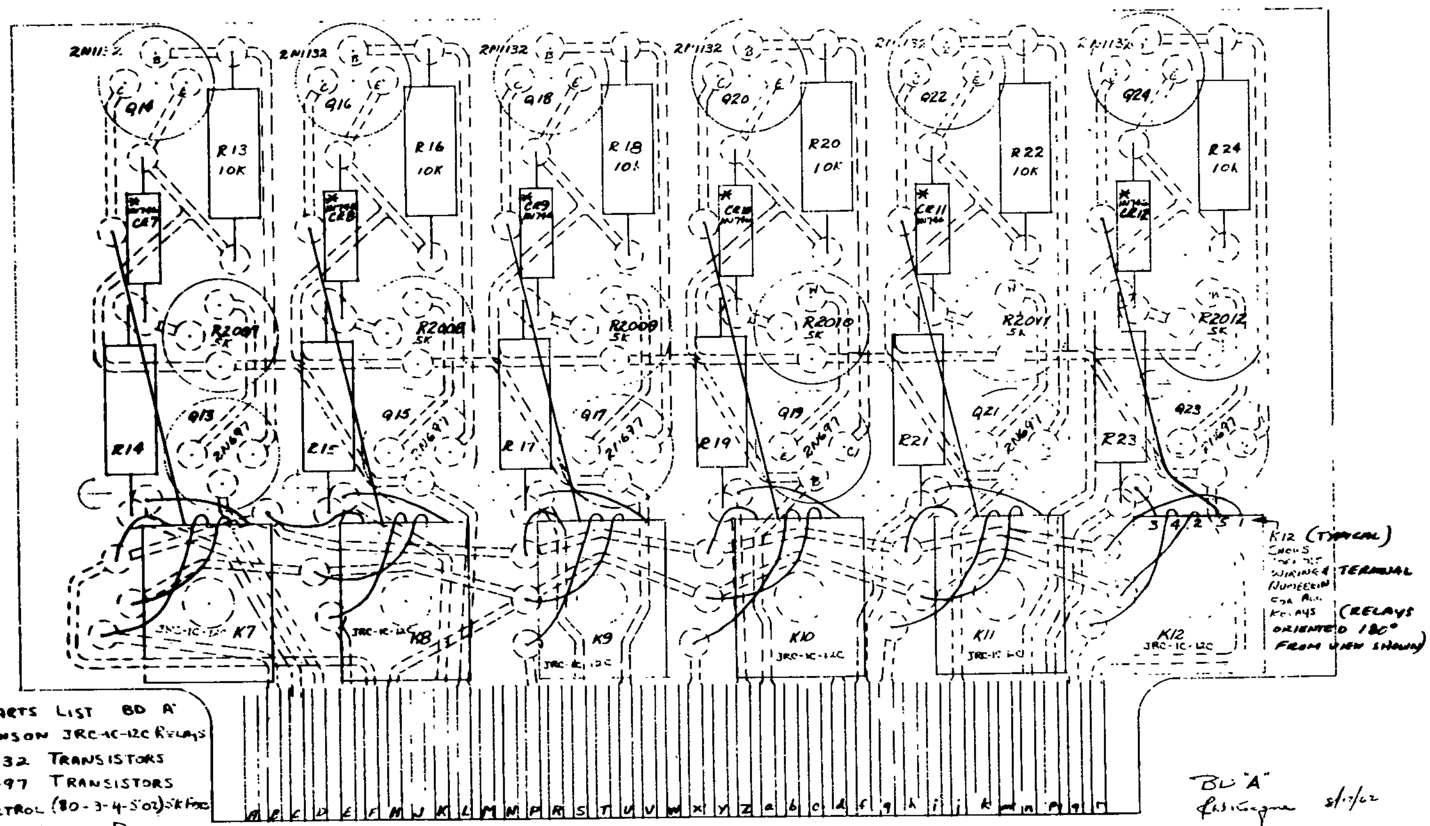
1


REVISIONS
DETAILS, FUEL CELL CONTROLLER
SK56122-595
GENERAL ELECTRIC
ALL HOLES .170 +.005 -.001 DIA UNLESS NOTED
G1 AS SHOWN
G2 OPP HAND TO G1

2

2D-25/26

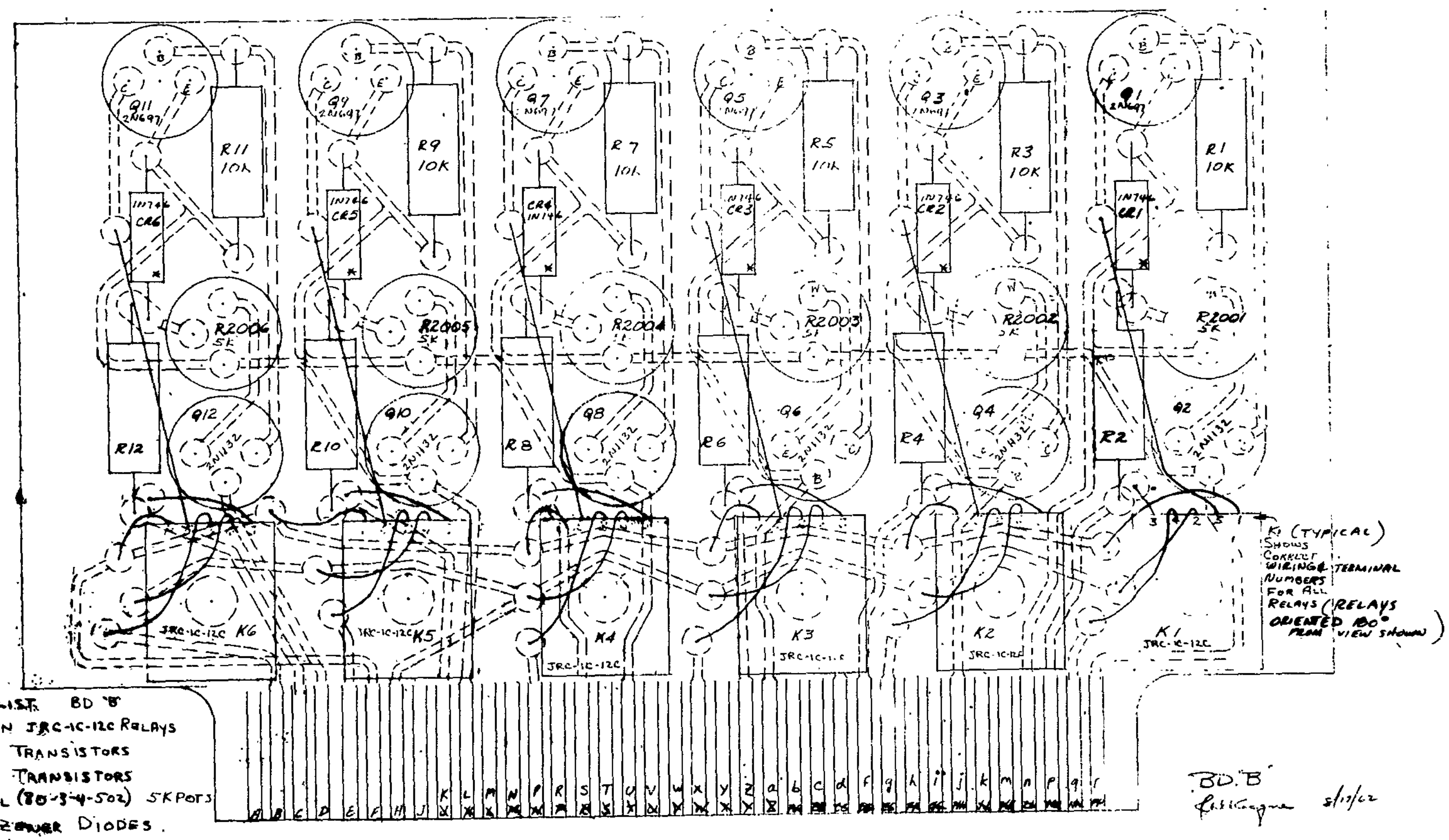
PRINTED CIRCUIT BOARD LAYOUT SKETCHES



BD "A"
5/1/62

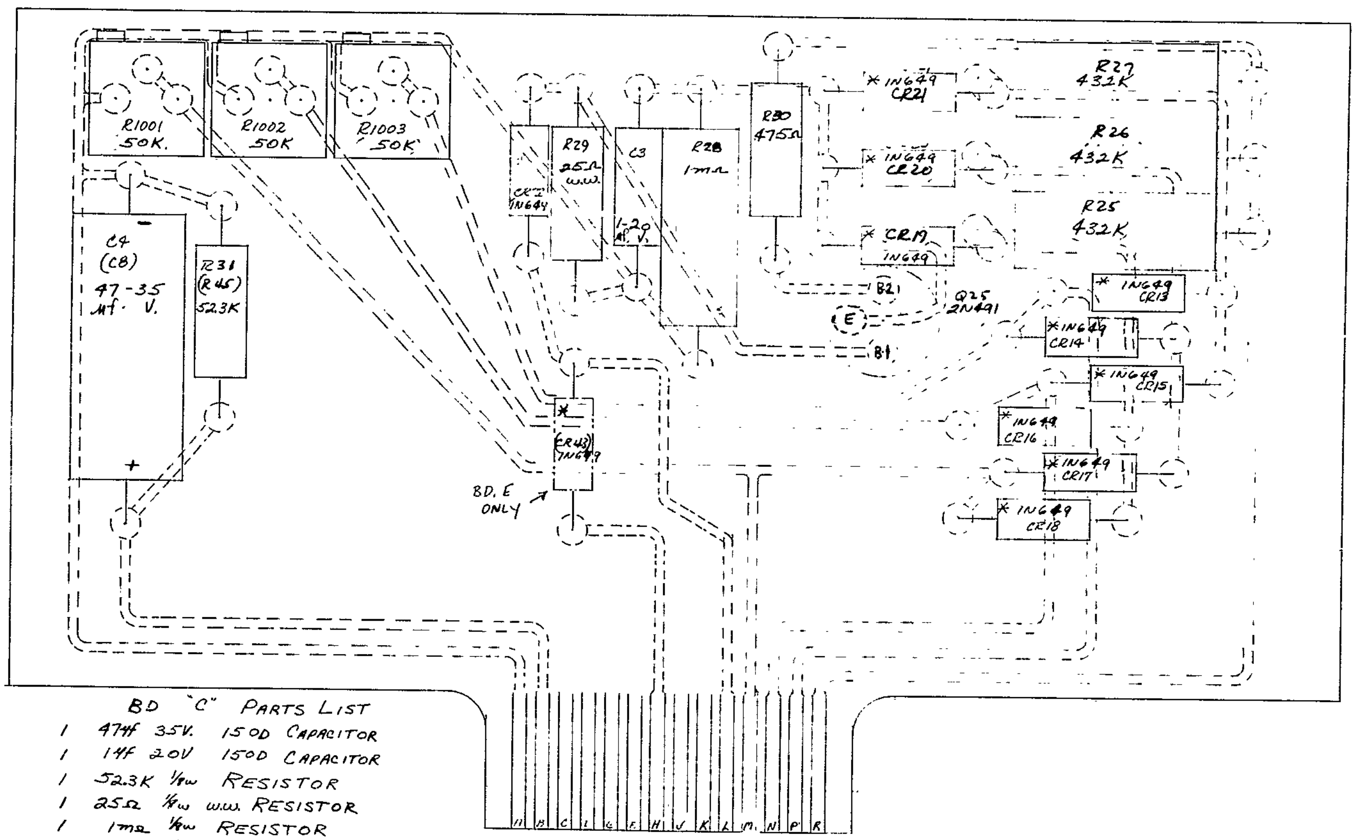
PARTS LIST BD A

- 6 BRANSON JRC-1C-12C RELAYS
- 6 2N1132 TRANSISTORS
- 6 2N697 TRANSISTORS
- 6 SPECTROL (80-3-4-502) 5K POT
- 6 IN746 ZENER DIODES
- 6 10K 1% NF60 RESISTORS
- 6 1.8K 1% NF60 RESISTORS



PARTS LIST BD 'B'

6 BRANSON JRC-1C-12C RELAYS
6 2N1132 TRANSISTORS
6 2N 697 TRANSISTORS
6 SPECTROL (80-3-4-502) 5K POTS
6 1N746 ZENER DIODES.
6 10K 1% NF60 RESISTORS
6 1.82 K 1% NF60 RESISTORS



BD "C" PARTS LIST

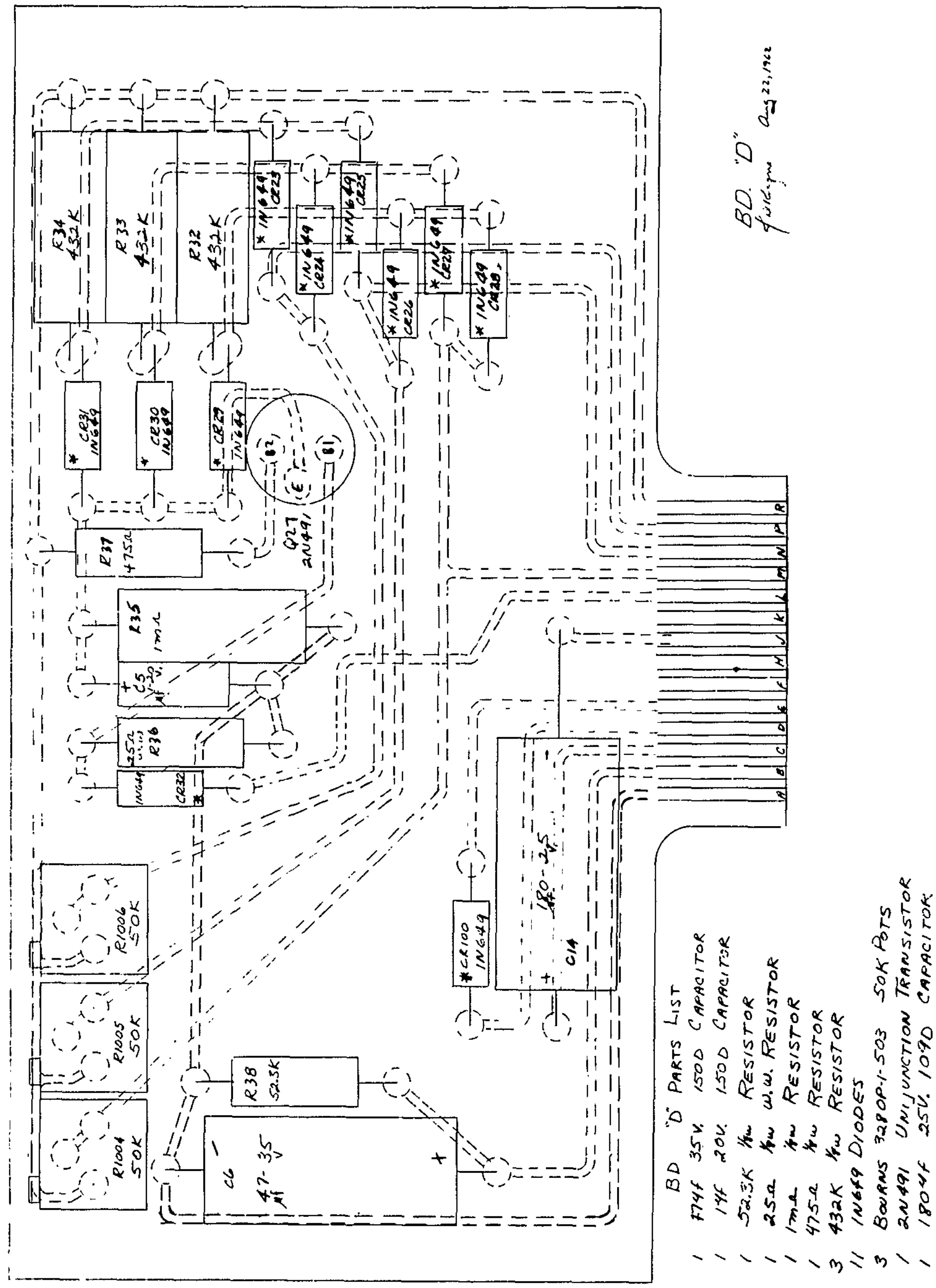
1 47μf 35V. 150D CAPACITOR
1 1μf 20V 150D CAPACITOR
1 52.3K 1/8w RESISTOR
1 25Ω 1/8w w.w. RESISTOR
1 1mΩ 1/8w RESISTOR
1 475Ω 1/8w RESISTOR
3 432K 1/8w RESISTOR
10 1N649 DIODES
3 BOURNS 3280P-1-503 50K POTS
1 2N491 UNIJUNCTION TRANSISTOR

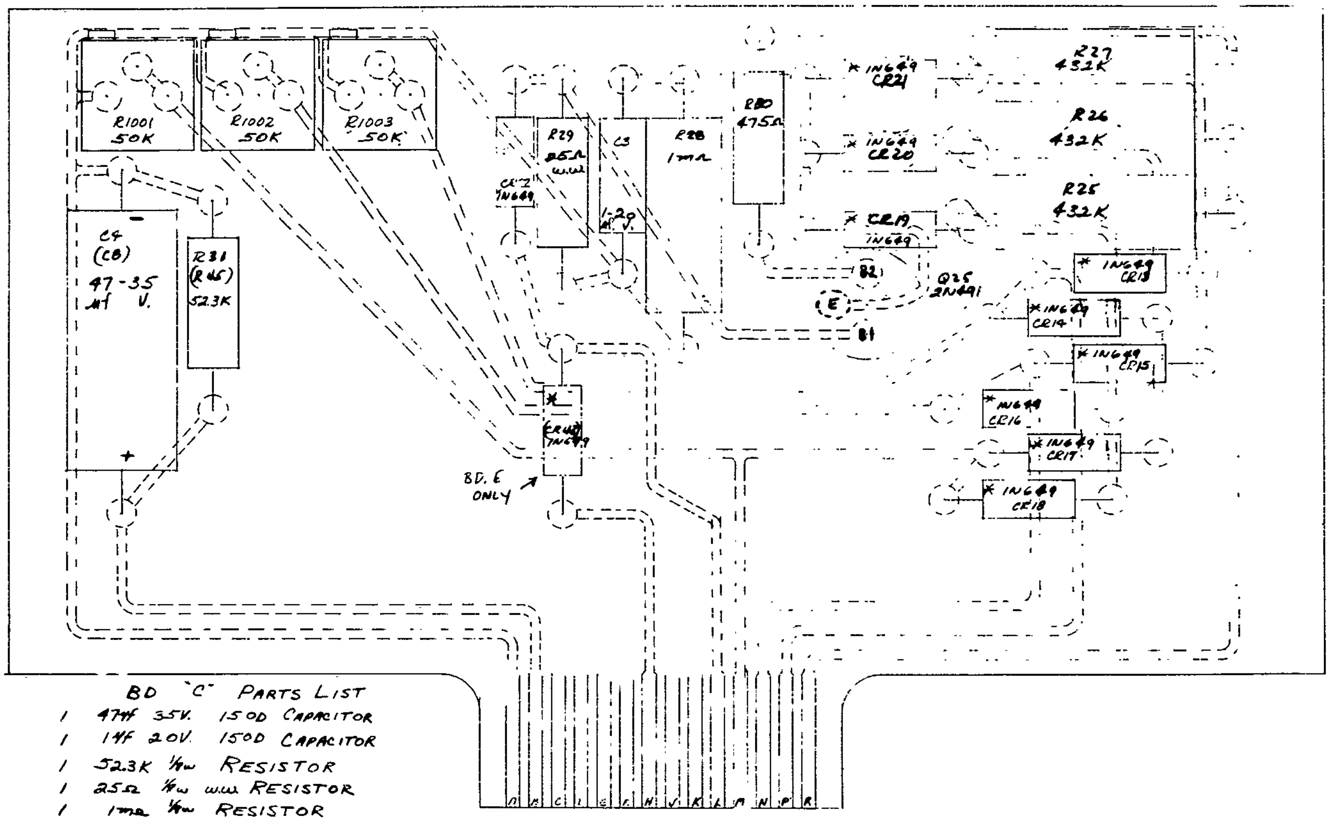
BD "E" PARTS LIST

1 47μf 35V. 150D CAPACITOR (C7)
1 52.3K 1/8w RESISTOR (R45)
1 1N649 DIODE (CR43)

BD. C&E

J. Rogers Aug 15, 1962


BD. "D"
Aug 22, 1962
R34 432K
R33 432K
R32 432K
CR31 1N649
CR30 1N649
CR29 1N649
Q27 2N491
R37 475Ω
R35 1mΩ
C5 1μf 20V.
R36 25Ω
CR32 1N649
R1006 50K
R1005 50K
R1004 50K
R38 52.3K
C6 47μf 35V
CR100 1N649
C14 180μf 25V.
BD "D" PARTS LIST
1 47μf 35V. 150D Capacitor
1 1μf 20V. 150D Capacitor
1 52.3K 1/4w Resistor
1 25Ω 1/4w W.W. Resistor
1 1mΩ 1/4w Resistor
1 475Ω 1/4w Resistor
3 432K 1/4w Resistor
11 1N649 Diodes
3 Bourns 3280P-1-503 50K Pots
1 2N491 Unijunction Transistor
1 180μf 25V. 109D Capacitor



BD "C" PARTS LIST

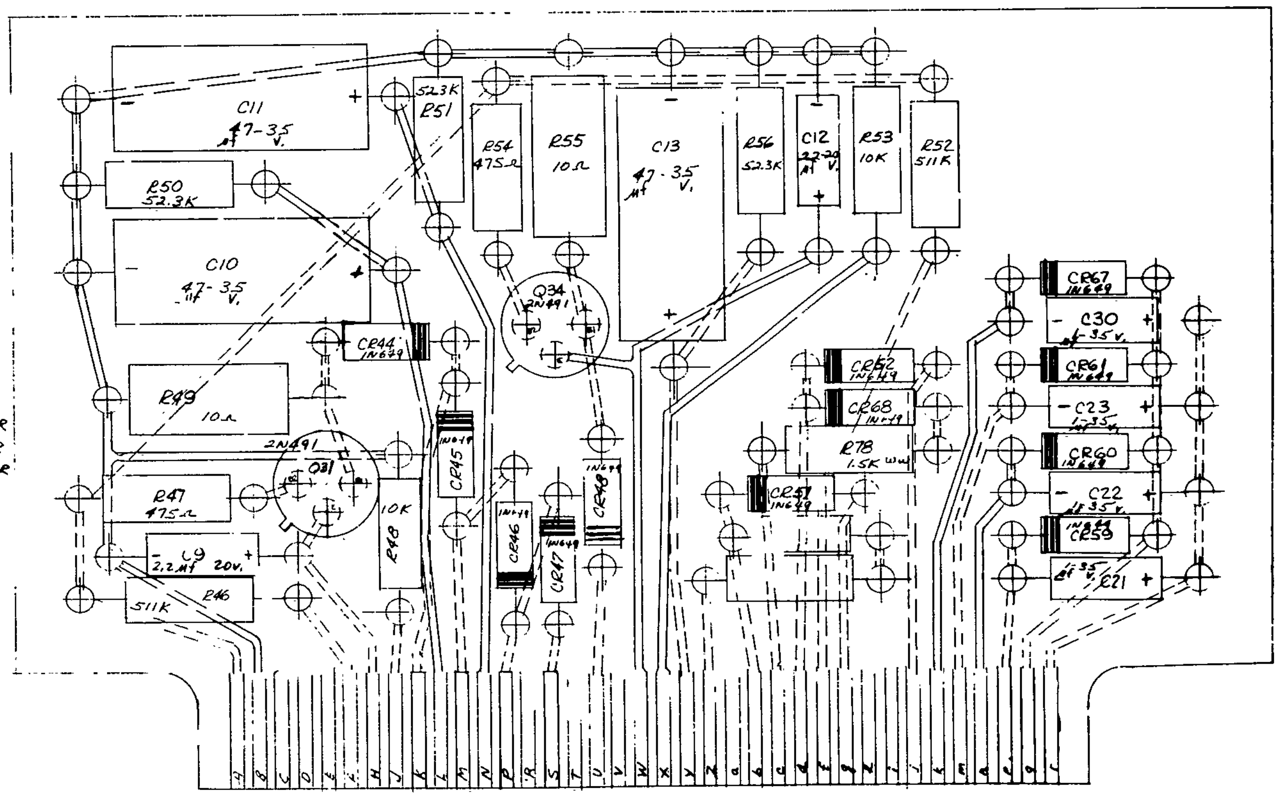
1 47µf 35V. 150D CAPACITOR
1 1µF 20V. 150D CAPACITOR
1 52.3K ¼w RESISTOR
1 25Ω ¼w ww RESISTOR
1 1mΩ ¼w RESISTOR
1 475Ω ¼w RESISTOR
3 432K ¼w RESISTOR
10 1N649 DIODES
3 BOURNS 3280P-1-503 50K POTS
1 2N491 UNIJUNCTION TRANSISTOR

BD "E" PARTS LIST

1 47µf 35V. 150D CAPACITOR (C8)
1 52.3K ¼w RESISTOR (R45)
1 1N649 DIODE (CR43)

BD. C&E

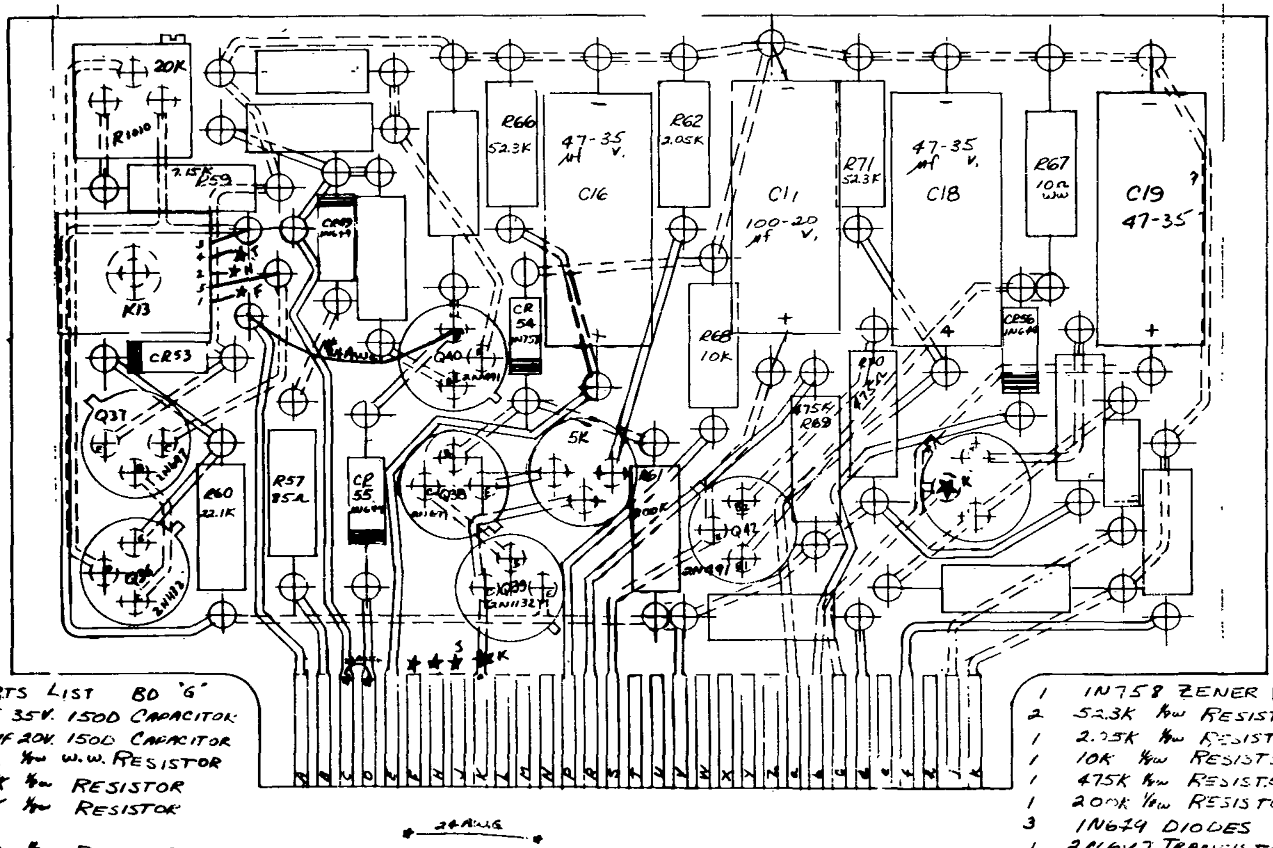
J. Rogers Aug 15, 1962



3D "F" PARTS LIS

3	47µf 35V.	150D	CAPACITOR
4	1µf 35V.	150D	CAPACITOR
1	2.2µf 20V	150D	CAPACITOR
2	511K 1/8w		RESISTOR
2	475Ω 1/8w		RESISTOR
2	10Ω 1/8w		w.w. RESISTOR
3	52.3K 1/8w		RESISTOR
2	10K 1/8w		RESISTOR
1	1.5K 1/8w		w.w. RESISTOR
12	1N649		DIODES
2	2N491		UNIJUNCTION TRANSISTORS

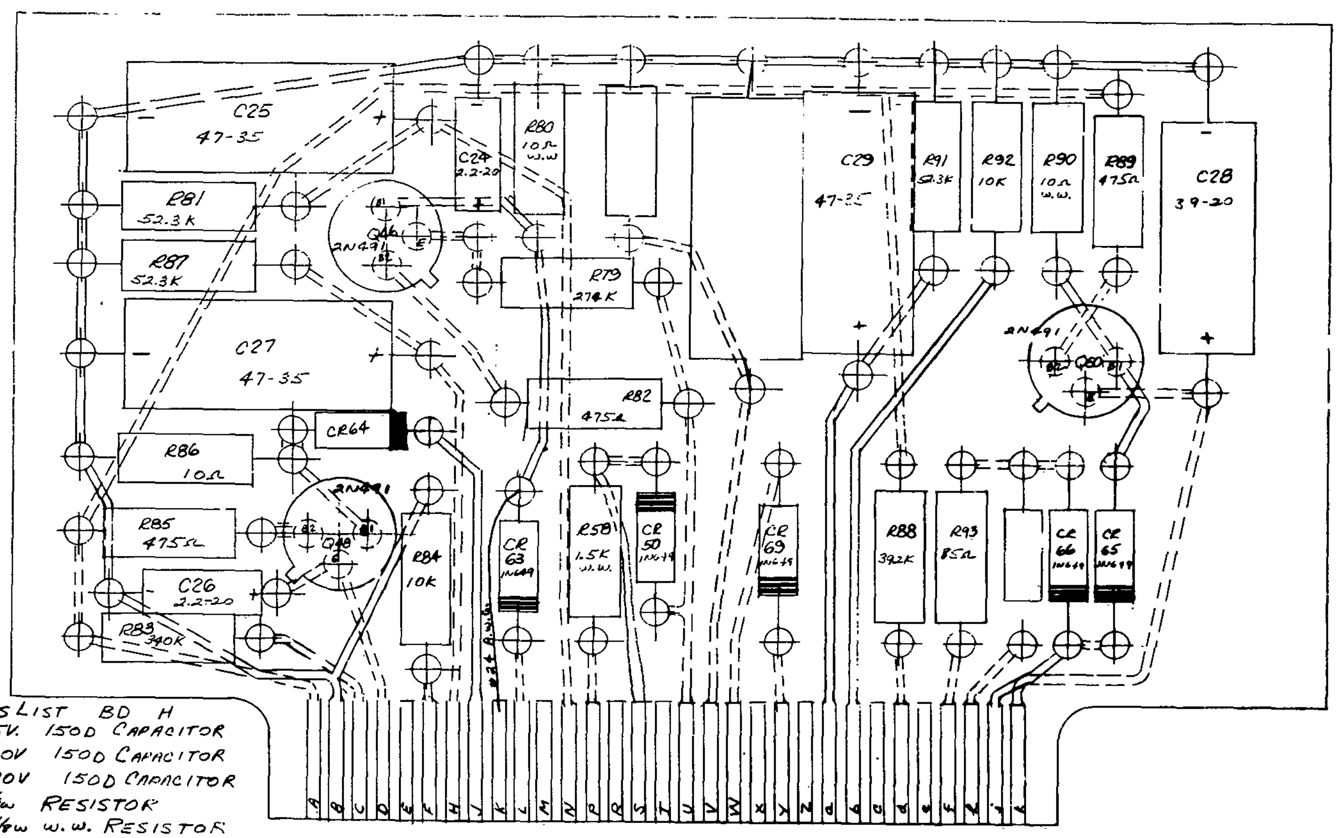
'G' BOARD



PARTS LIST BD 'G'

2 47μf 35V. 150D CAPACITOR
2 100μf 20V. 150D CAPACITOR
1 85Ω ¼w w.w. RESISTOR
1 22.1K ¼w RESISTOR
1 7.15K ¼w RESISTOR
1
3 475Ω ¼w RESISTOR
1 10Ω ¼w w.w. RESISTOR

1 1N758 ZENER DIODE
2 52.3K ¼w RESISTOR
1 2.05K ¼w RESISTOR
1 10K ¼w RESISTOR
1 475K ¼w RESISTOR
1 200K ¼w RESISTOR
3 1N629 DIODES
1 2N647 TRANSISTOR
1 2N1132 TRANSISTOR
1 2N491 UNIJUNCTION TRANSISTOR

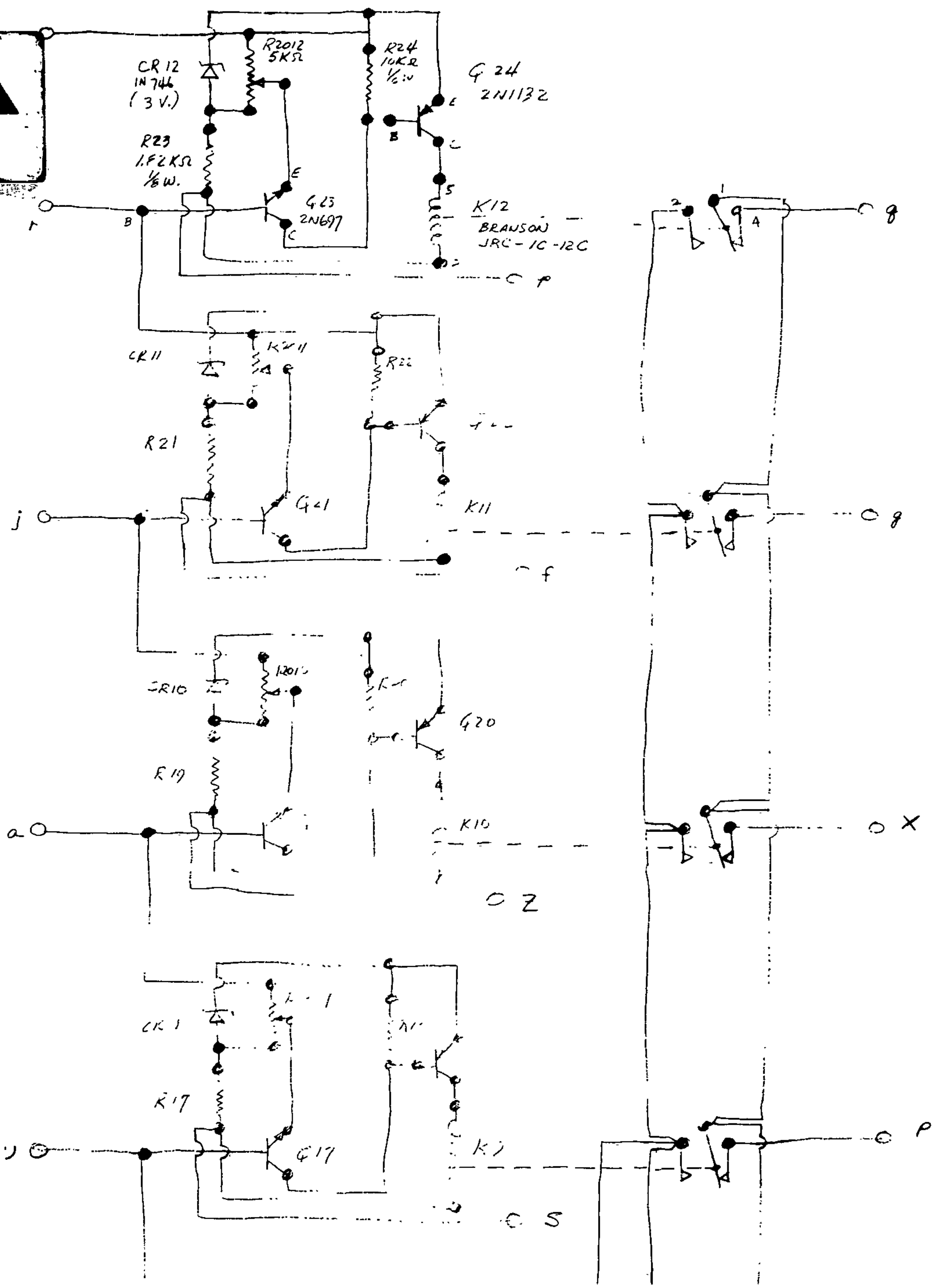


PARTS LIST BD H

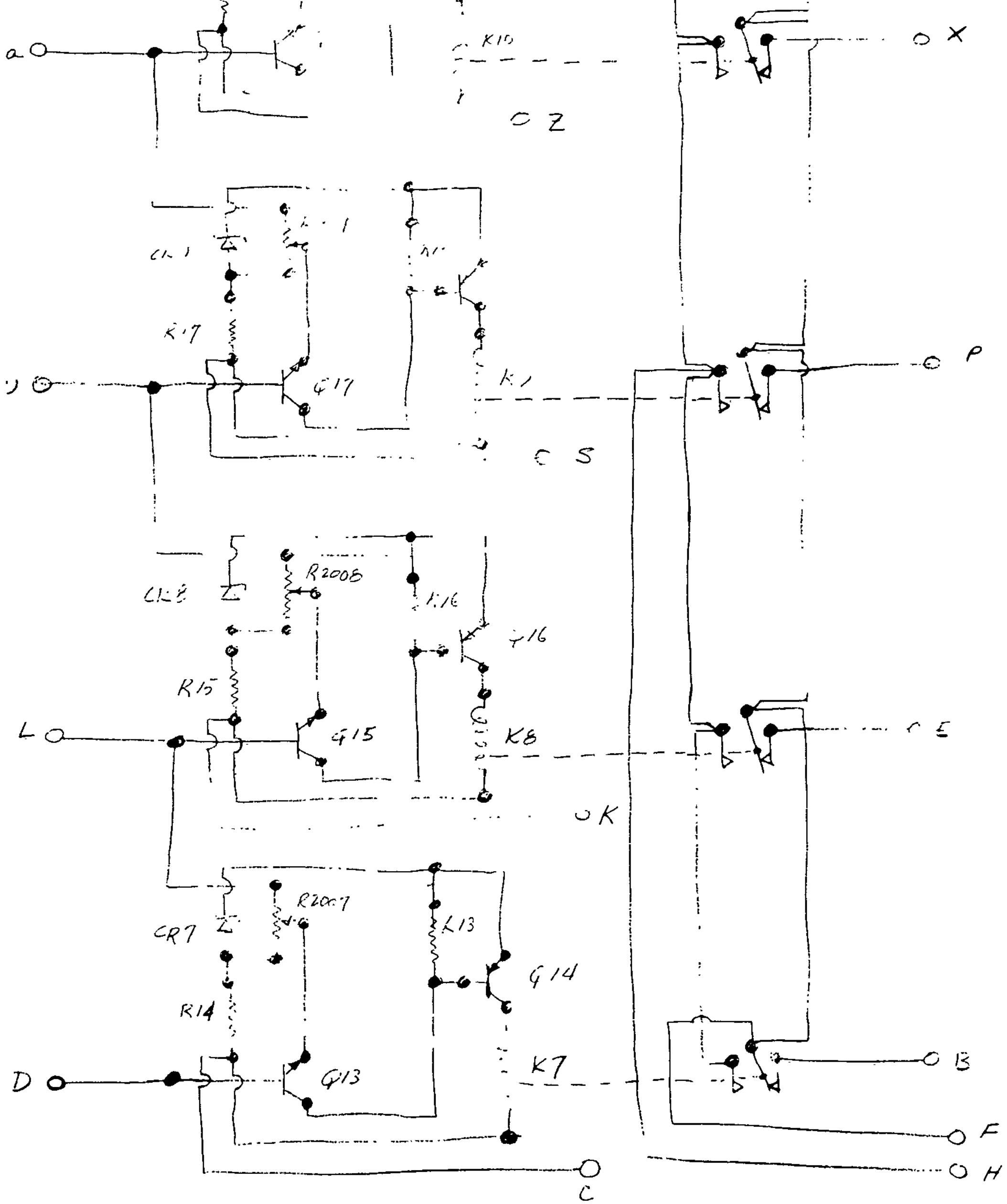
4	47μf 35V.	150D	CAPACITOR
1	100μf 20V	150D	CAPACITOR
2	2.2μf 20V	150D	CAPACITOR
1	340K	1/4w	RESISTOR
3	10Ω	1/4w	W.W. RESISTOR
3	475Ω	1/4w	RESISTOR
4	52.3K	1/4w	RESISTOR
2	10K	1/4w	RESISTOR
1	274K	1/4w	RESISTOR
1	392K	1/4w	RESISTOR
1	1.5K	1/4w	W.W. RESISTOR
1	85Ω	1/4w	W.W. RESISTOR
6	1N649		DIODE
3	2N491		UNIJUNCTION TRANSISTOR

PRINTED CIRCUIT BOARD SCHEMATICS

1

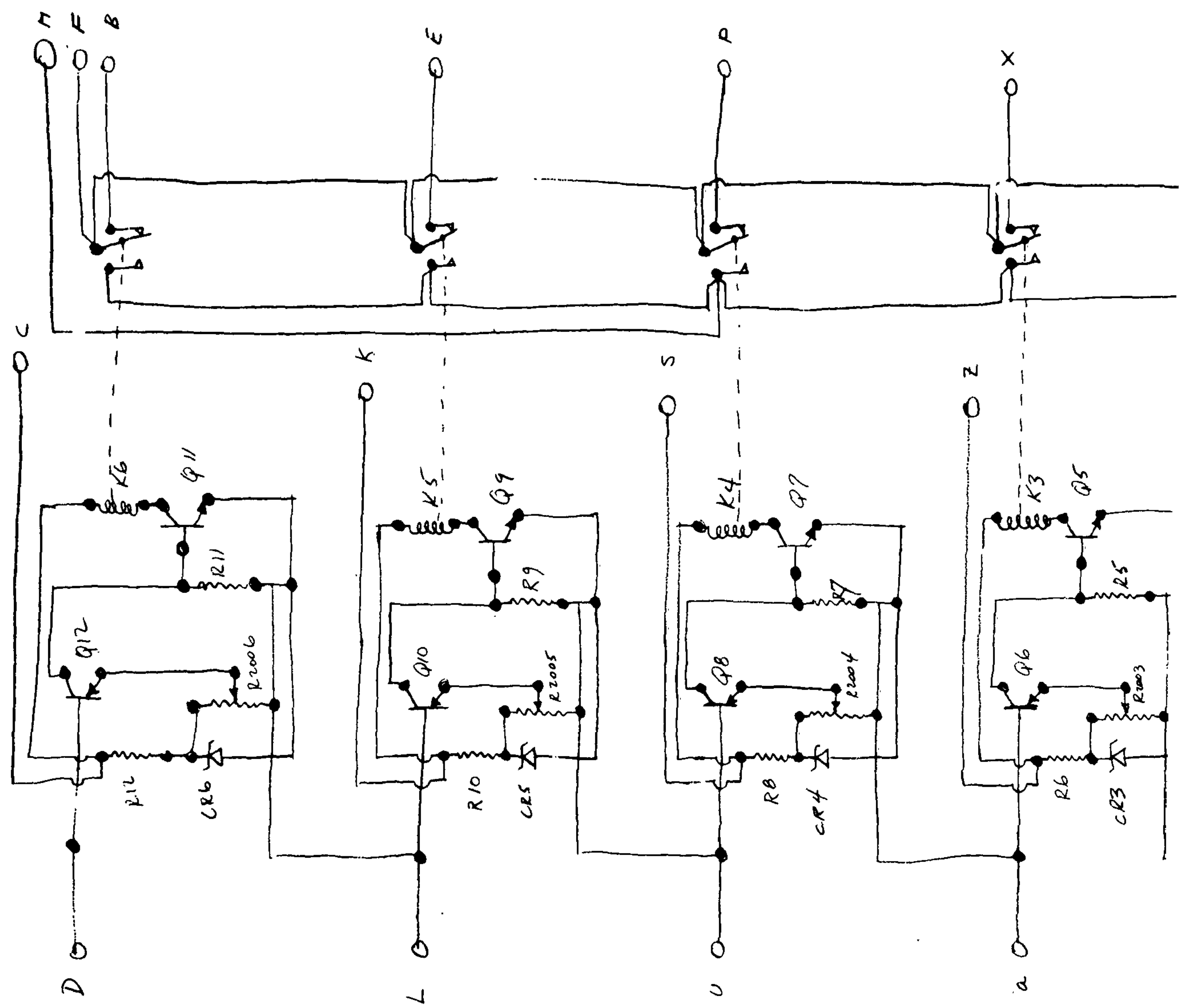


CR 12
1N746
(3 V.)
R2012
5KΩ
R24
10KΩ
Q 24
2N1132
R23
1.F2KΩ
⅛W.
Q23
2N697
K12
BRANSON
JRC-1C-12C
r
B
p
q
CR11
K211
R22
R21
j
Q21
K11
g
f
CR10
R201
Q20
R19
a
K10
x
Z
CK1
K17
Q17
p
S

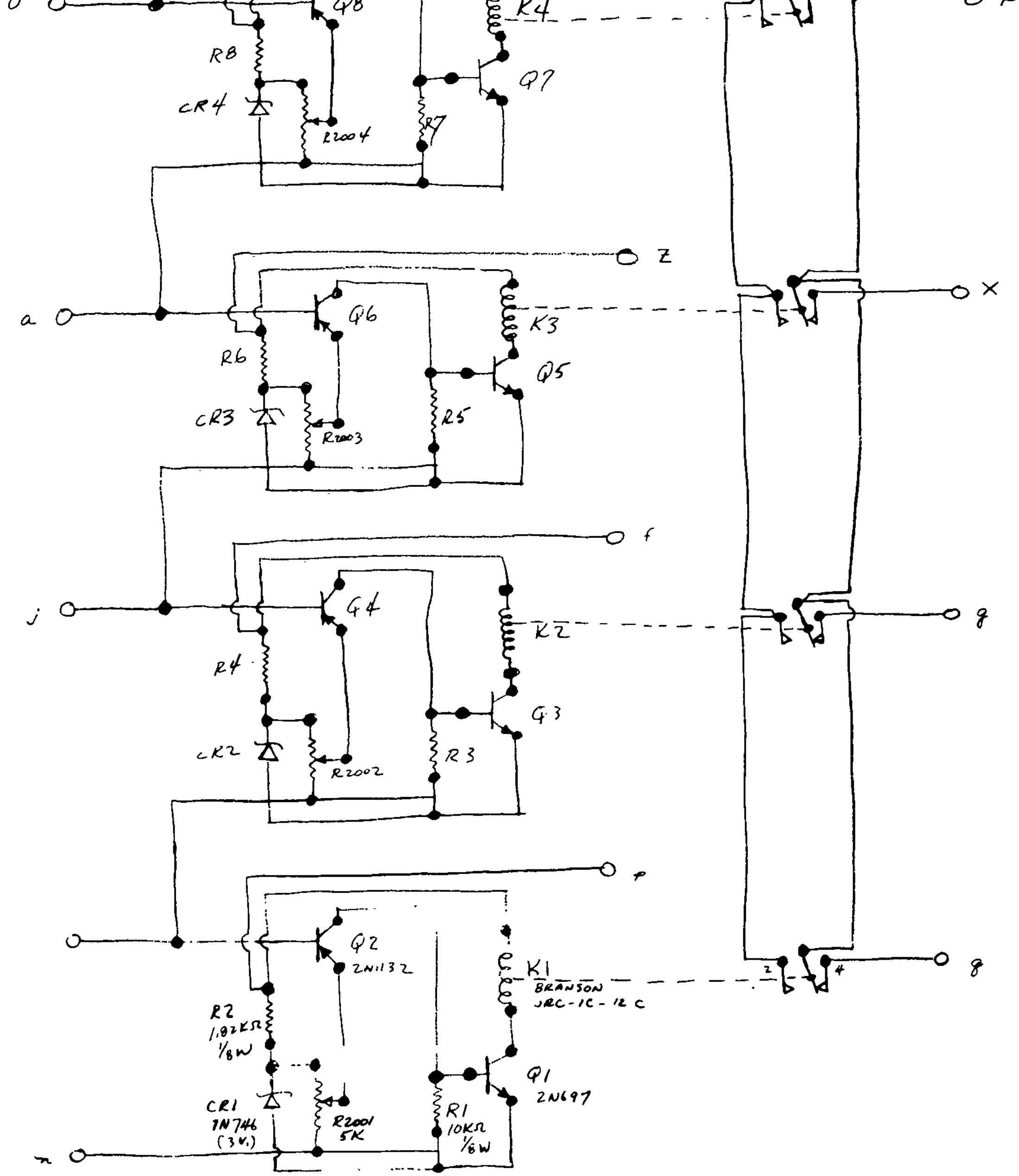


BOARD "A"
10/8/62

SPARE FINGER TERMINALS:
A, J, M, N, R, T, V, W,
Y, b, c, d, h, i,
k, m


H
F
B
E
P
X
C
K
S
Z
K6
Q11
R11
Q12
R2006
R12
CR6
K5
Q9
R9
Q10
R2005
R10
CR5
K4
Q7
R7
Q8
R2004
R8
CR4
K3
Q5
R5
Q6
R2003
R6
CR3
D
L
U
a

1

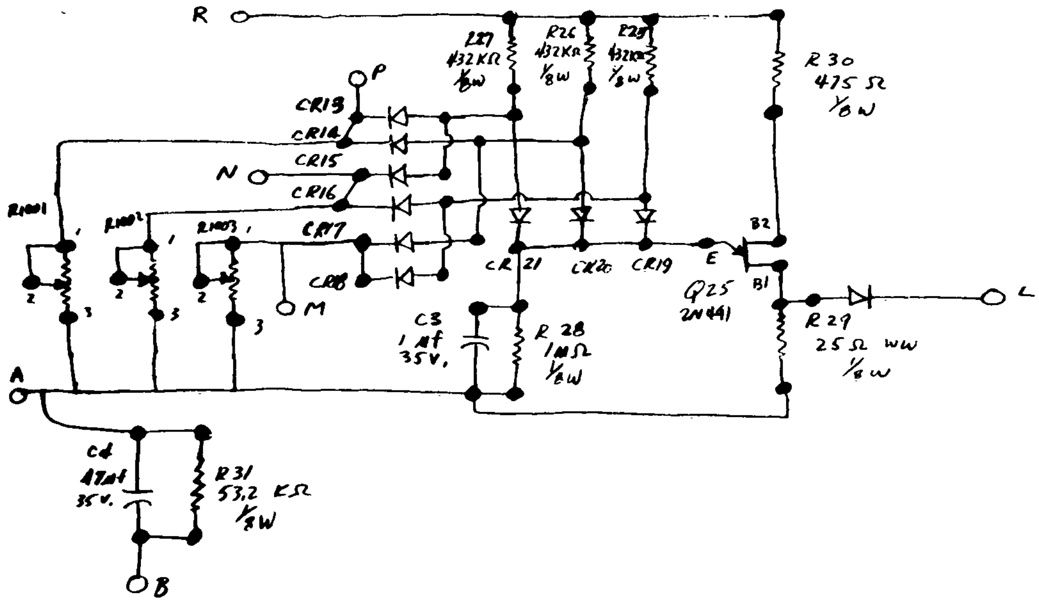


SPARE FINGER TERMINALS
A, J, M, N, R, T, V, W,
Y, b, c, d, h, i, k, m

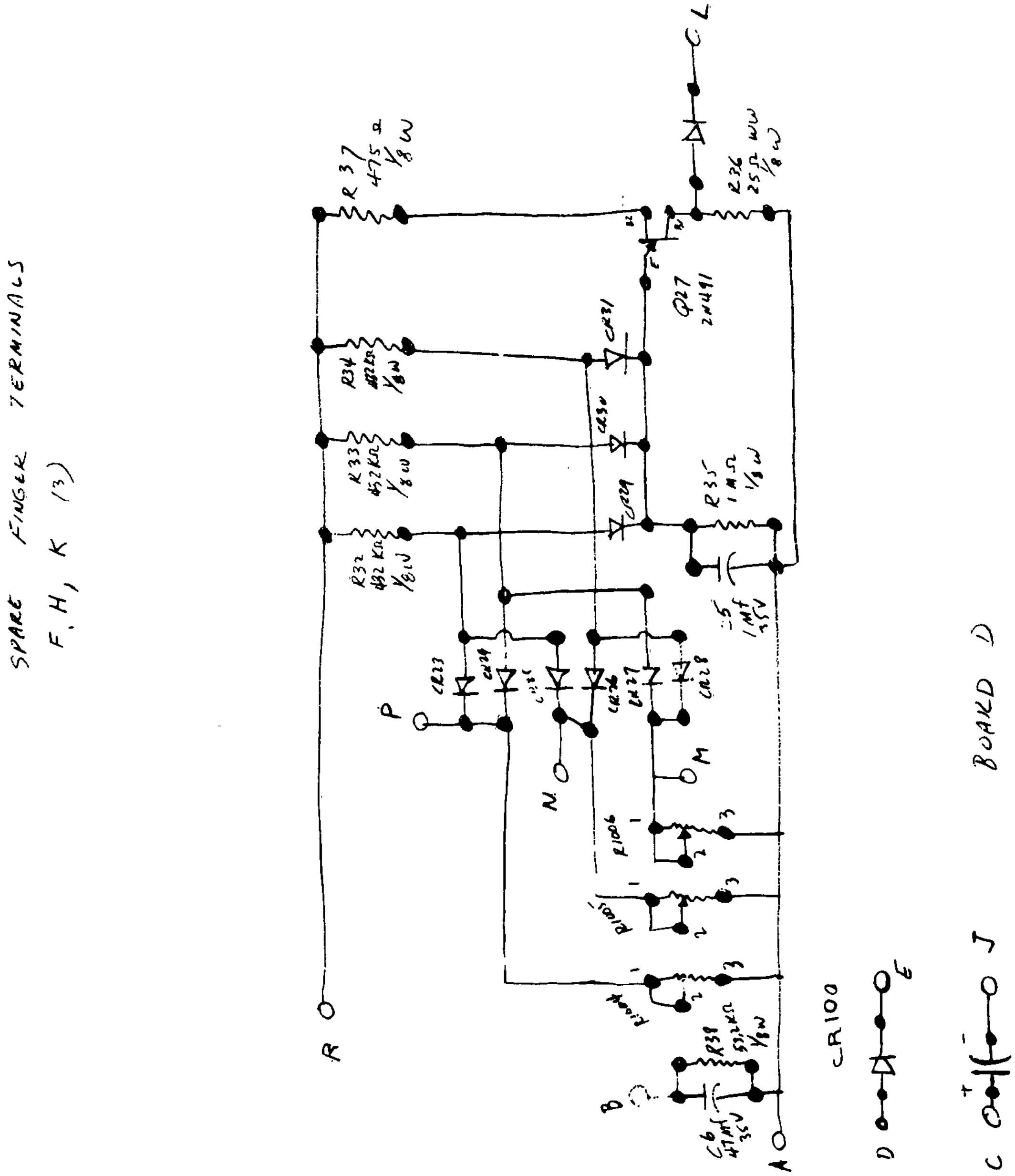
BOARD B
10/8/62

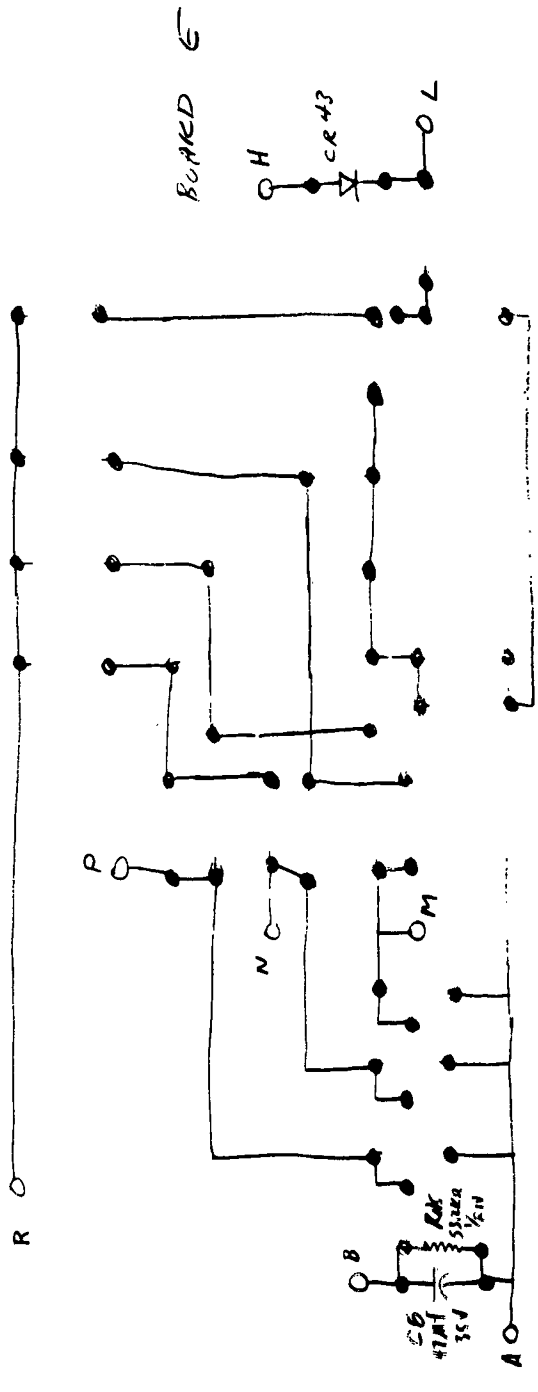
2

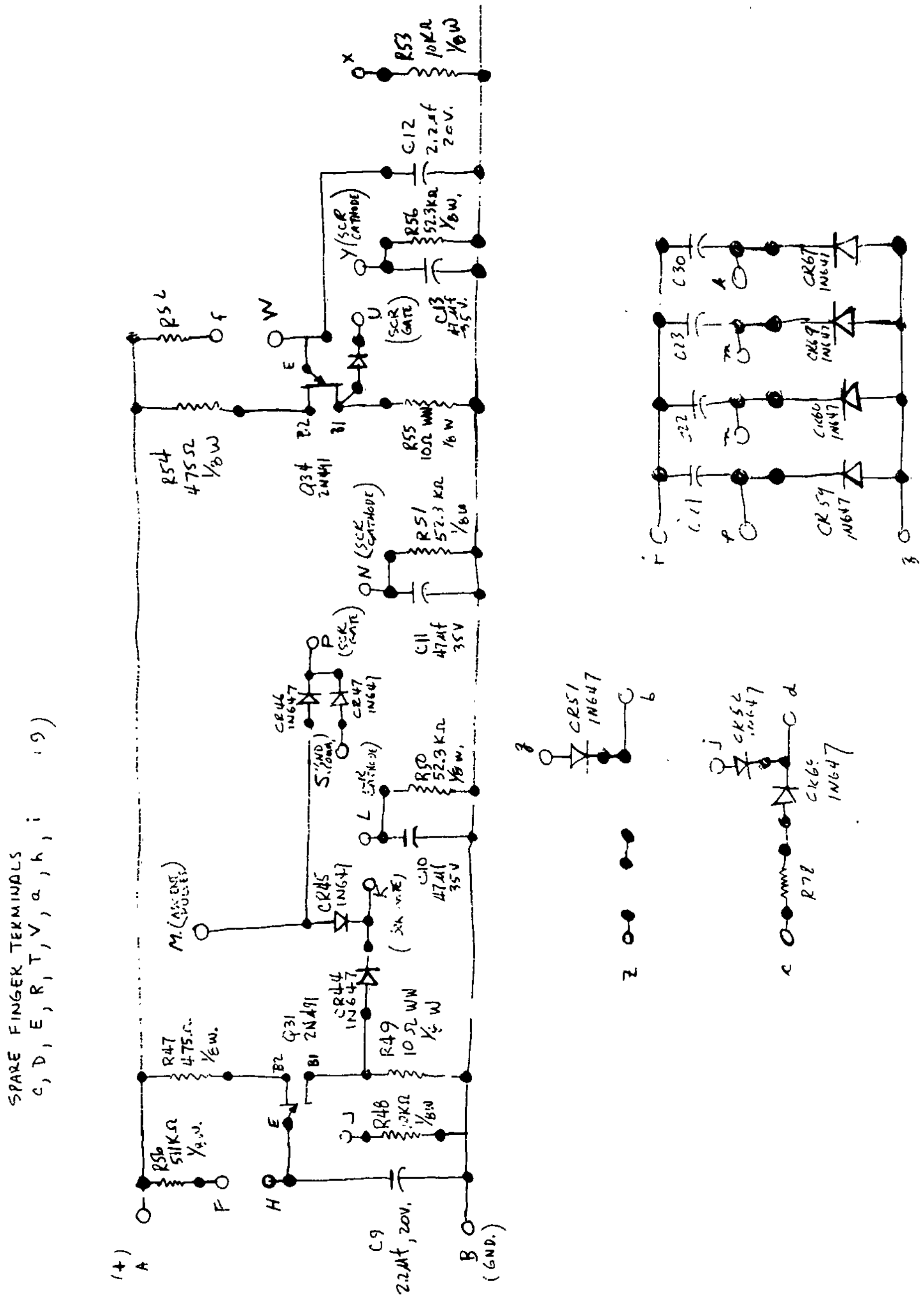
SPARE FINGER TERMINALS
C, D, E, F, J, K (6)
H (BD 'C')



BOARD

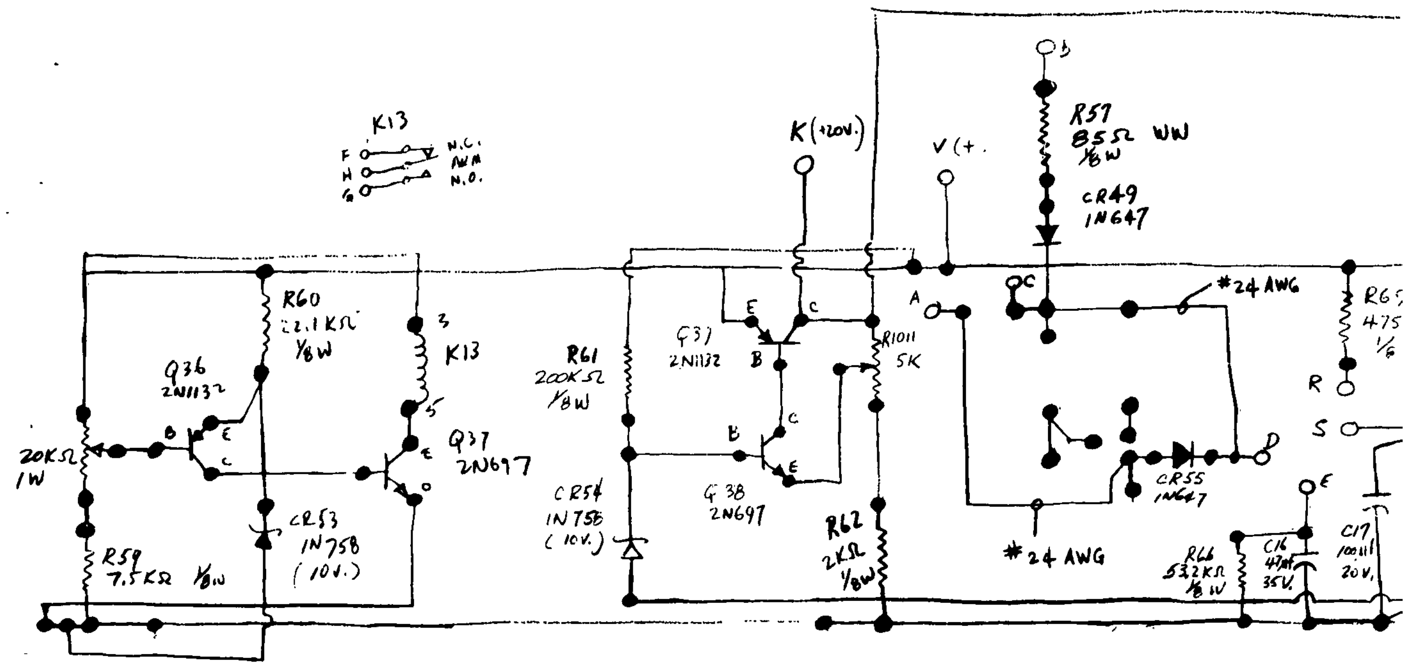

SPARE FINGER TERMINALS
F, H, K (3)
BOARD D
R37 475Ω 1/8W
R34
R33 452KΩ 1/8W
R32 432KΩ 1/8W
R35 1MΩ 1/8W
R36 25Ω WW 1/8W
Q27 2N491
CR100
C14
R
P
N
M
A
B
C
D
E
J
L


BOARD 6
H
CR 43
L
P
N
M
R
B
A
C6


SPARE FINGER TERMINALS
BOARD "F"

SPARE FINGER TERMINALS

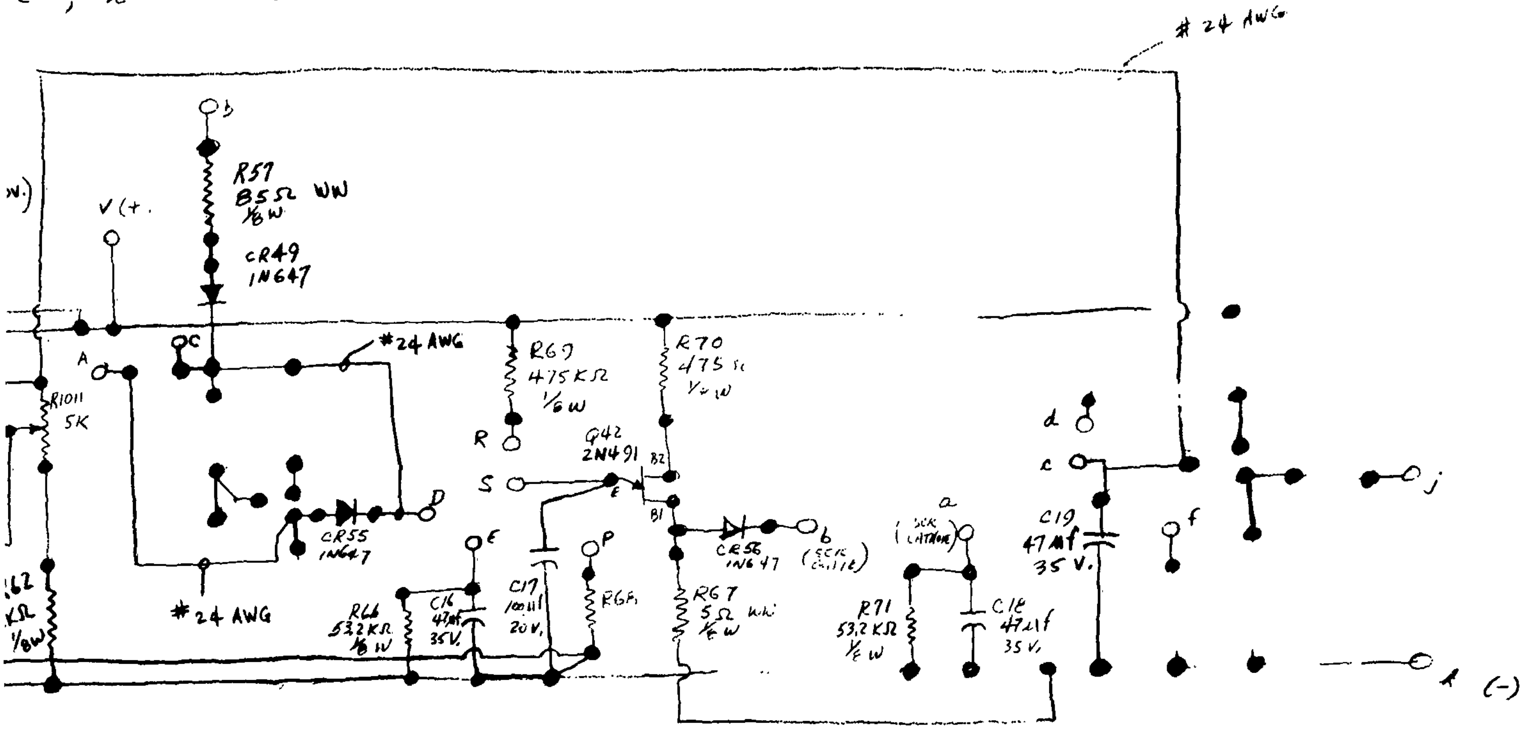
L, M, N, T, U, W, X, Y, Z, e, h (14)



BOARD G

1

e , h (14)



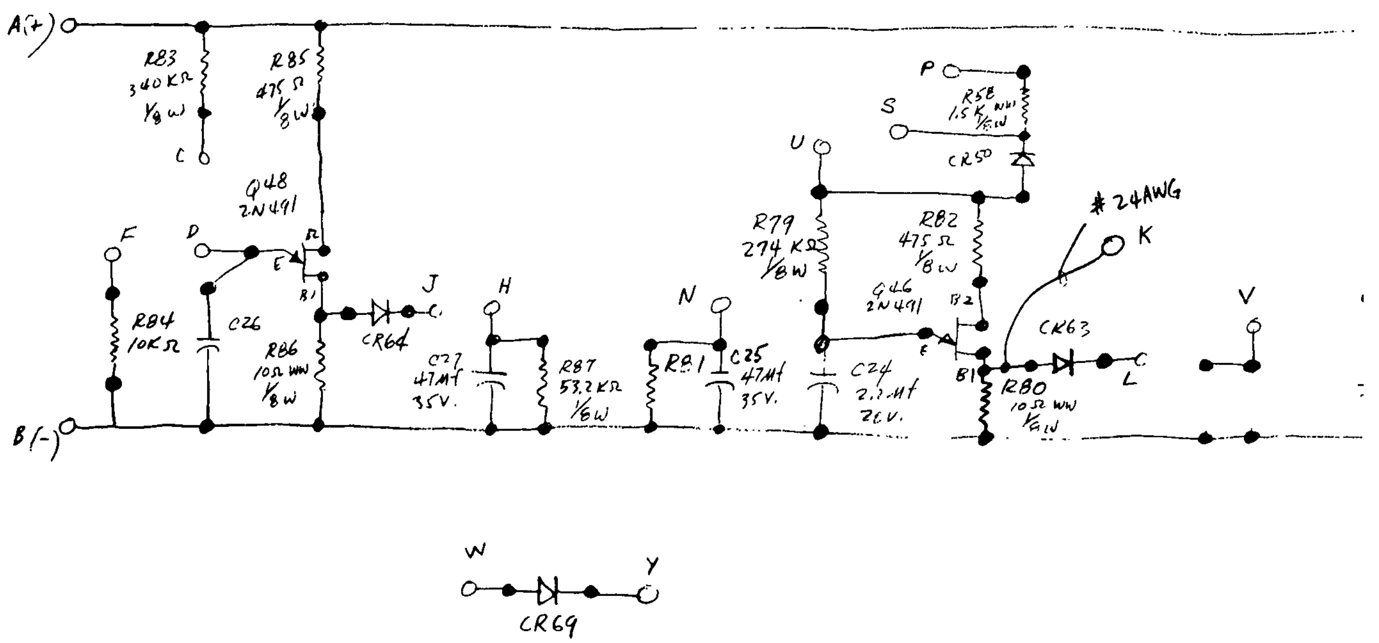
BOARD G

10/8/62

2

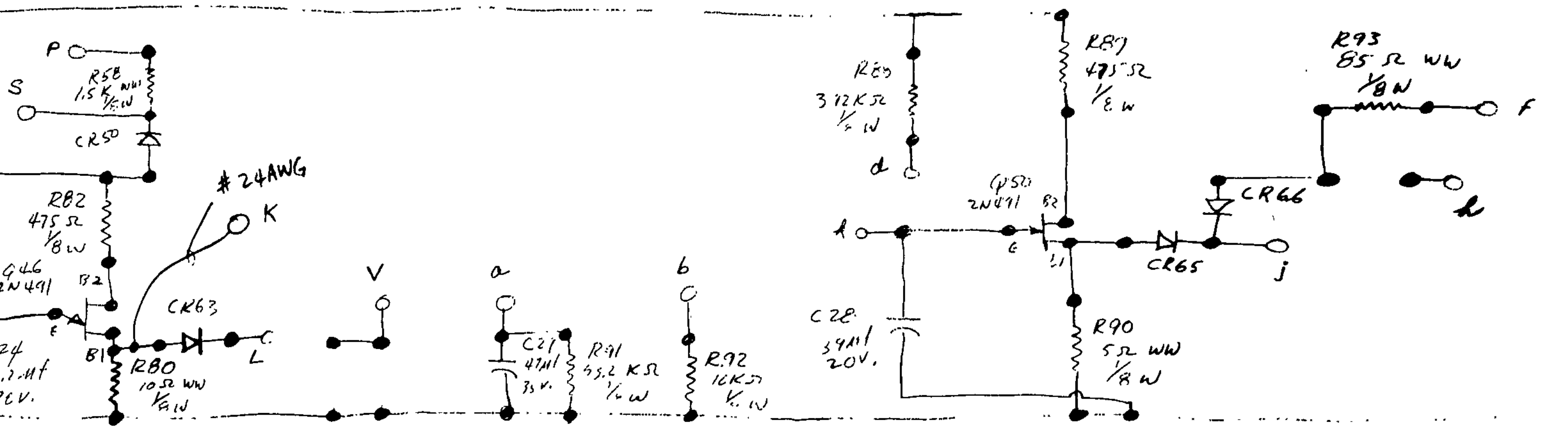
2D-47/2D-48

SPARE FINGER TERMINALS
E, M, R, T, X, Z, c, (8)



1

c ,   (8)



BOARD H
10/8/62

2

APPENDIX 3A

FUEL SUPPLY SUBSYSTEM

SPECIFICATIONS, DRAWINGS AND PHOTOGRAPHS

Specification No.: SVS 7051
Date: August, 1962

General Electric Company
Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555
Philadelphia 1, Pennsylvania

Component Specification for a

Valve, Pneumatic-Solenoid, Fill and Dump

Prepared by: /s/ H. P. Marderness Date: 10/17/62
H. P. Marderness
Engineer - HOPE
Room 2626U, Ext. 5829

Approved by: ____________________ Date:
R. J. Barchet
System Engineer - HOPE
Room 2626U, Ext. 5829

Specification No.: SVS 7051
Date: August, 1962

General Electric Company
Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555
Philadelphia 1, Pennsylvania

Valve, Pneumatic-Solenoid, Fill and Dump

1. SCOPE

1.1 General. This specification establishes the design, fabrication and test requirements for a satellite pneumatic solenoid valve, hereinafter referred to as the unit. This unit will be employed in a subsystem for the purpose of permitting flow into the gas storage tanks during fuel charging and for permitting flow from the gas storage tank to overboard when the unit is energized and preventing gas flow in either direction when de-energized.

1.1.1 The requirements of this specification are detailed only to the extent considered necessary to obtain desired performance and reliability.

1.1.2 The following classes of the unit are described herein:

SVS 7051 A

1.1.3 Neither the acceptance by the Purchaser of the unit(s) specified herein or of any of the data specified by this detail requirement and others forming part of this specification nor any review or approval by the Purchaser of Vendor drawings or other documents nor the acceptance by the Vendor of design recommendations made by the Purchaser, shall be construed as releasing or, modifying in any way the Vendor's responsibility to meet all of the requirements of this specification.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of initiation for bids, form a part of this specification.

Military Specifications

MIL-A-8625 Anodic Coatings for Aluminum and Aluminum Alloys.

MIL-C-5541 Chemical Films for Aluminum and Aluminum Alloys.

MIL-D-70327 Drawings, Engineering and Associated Lists.

MIL-E-4970 Environmental Testing, Ground Support Equipment.

MIL-I-26600 Radio Interference.

MIL-M-3171 Magnesium Alloy, Processes for Corrosion, Protection of.

MIL-Q-9858 Quality Control System Requirements.

General Electric Specifications

118A1526 Identification Marking.

118A1630 Oxygen System Components, Cleanliness - Control for.

Military Standards

MIL-STD-129 Marking for Shipment and Storage.

MIL-STD-202 Test Methods for Electronic Component Parts.

MS 33540 Safety Wiring, General Practices for.

MS 33588 Nuts and Plate Nuts, Self-Locking.

AND 20995 Wire, Lock.

Military Handbooks

H - 28 Screw Thread Standards for Federal Services.

2.2 Precedence. In the event of conflict between the Purchase Order, this specification or subsidiary specifications the order of precedence shall be as follows:

1st - Purchase Order,

2nd - this Specification,

3rd - Subsidiary Specifications (all specifications referenced herein).

3. REQUIREMENTS

3.1 Identification of Unit. Identification and serializing of units shall be in accordance with General Electric Specification 118A1526 and in the location shown on the applicable General Electric drawing. Nameplates shall be attached with threaded fasteners and lockwired against loosening or falling off.

All other methods of attachment shall be prohibited except for the following:

(a) Threaded screws with nylon locking devices may be used.

(b) Rivets may be used in special cases only; such as on sheet metal shields, covers, or boxes. Where used, the upset end of the rivet shall be on the identification surface of the nameplate so that faulty workmanship may be inspected and so that attachment may be recognized.

3.2 Consistency and Identification of Design

3.2.1 Interchangeability. All parts or combination of parts (subassemblies) having the same manufacturer's number shall be directly and completely interchangeable with each other with respect to safety, durability, weight, installation, spare parts and performance. Changes in manufacturer's part numbers shall be subject to approval by the purchaser as specified in Paragraph 3.2.2 and shall be governed by the drawing requirements of Specification MIL-D-70327.

3.2.2 Change in Design. No changes shall be made in the design, material, process, sub-vendors or construction of the unit from the model which has been approved and released by the Purchaser, except when such changes are approved by the following methods:

(a) Any change affecting weight, interchangeability, process, performance, durability, safety, material, spare parts, model or assembly number, sub-vendors (including the vendor's facility), any specification control drawing requirements, cost or delivery dates shall be accompanied with official substantiation of qualification test data and drawings clearly illustrating the proposed change. Approval by the Purchaser is required prior to introduction of all such changes. Upon approval of these changes by the Purchaser of the parts affected, engineering data shall be furnished in accordance with Paragraph 3.5.

Model or assembly number changes shall be made in conformance with Specification MIL-D-70327.

(b) Changes not restricted by Paragraph 3.2.2(a) may be adopted by the vendor. Upon adoption of such changes, engineering data shall be furnished as specified in Paragraph 3.5. Final acceptance of each unit will be at the discretion of the Purchaser upon review of the data to be provided with each unit as specified in paragraph 3.5.2.

3.3 Workmanship. The unit shall be manufactured, assembled and tested in a thoroughly workmanlike manner. Particular attention shall be given, as applicable, to neatness and thoroughness of manufacture of parts, assembly, sub-assembly inspections, final assembly and inspection and final assembly tests. In general the quality control requirements shall conform to applicable portions of MIL-Q-9858.

3.4 Productiveness. The unit shall be designed for optimum employment of mass production techniques consistent with the requirements of this specification; particularly with regard to non-susceptability of reliability of the unit to manufacturing, assembly and test techniques.

3.5 **Drawings and Data List.** **The vendor shall supply the Purchaser with the following material and information, the cost of which shall not be included in the price of the units, but shall be costed separately.**

3.5.1 **The following shall be supplied within not less than 30 days prior to delivery of the first unit.**

3.5.1.1 **A complete set of reproducible copies of drawings (assembly, subassembly, and detail), parts list, provisioning parts breakdown list, material specification, heat treat and finish specifications and supplier of each part and process.**

3.5.1.2 A list of all detail parts which require selective assembly.

3.5.1.3 A list of critical and/or strategic materials used.

3.5.1.4 A list and description of any special tools required for disassembly, reassembly, and adjustment. The number of these items shall be kept to a minimum.

3.5.1.5 A report showing the performance and effects thereon of range in tolerances, temperatures, pressures, flow, transients, etc.

3.5.1.6 An inspection procedure manual. List of all subassembly tests planned to acquire assurance, during build-up of the unit, that the design intent exists in each unit; i.e., force margins, leakages, etc., and tests conducted on the completed unit.

3.5.1.7 A manual showing assembly and test procedures.

3.5.2 Each unit when delivered shall be accompanied by a detailed inspection record for the unit giving the information specified in 3.5.1.6. There shall have been 100% inspection of all parts, sub-assemblies and complete assembly with regard to all characteristics except for characteristics that would require destructive testing. In general, no deviation will be accepted. Any deviations existing shall be tabulated in a separate listing. Only authorized General Electric Company, MSD personnel may approve any deviation.

3.5.3 On a monthly basis a report shall be supplied with a tabulation relating the number of units sent to test, the number of failures (normal adjustments are not to be considered failures), the nature of the malfunction, the corrective action taken, the number of units that failed in the second time to test, etc., accounting for each unit that was sent to test.

3.6 Securing of Threaded Parts and Adjustments.

3.6.1 All internal or externally located nuts, screws, caps, plugs, or other movable parts shall be either positively locked or safety wired in accordance with MS33540 and drawing AND 20995 or other means approved by the purchaser.

3.6.2 When a seal is used to provide security against tampering with, or unauthorized adjustment, of the unit, the seal shall be made of a light-weight, non-corrosive material such as aluminum and preferably shall be of a tubular configuration. Lead seals shall not be used. The seal shall be secured in such a manner that under no circumstances will the seal break loose. It shall be located between secured elements rather than after the last lockwired element.

3.7 Screw Threads

3.7.1 Threads shall be in conformance with Handbook H-28. No tapered pipe threads shall be used.

3.7.2 Self-Locking Nuts. If self-locking nuts are used, they shall be made by an approved Vendor. The use of self-locking nuts shall be in accordance with requirements of MS33588, paragraphs 1 and 2 and 5 through 8. Bolts shall extend through nuts at least the full chamfer plus one and one-half pitches.

3.7.3 Inserts. Threads in "soft" metals; i.e., aluminum alloys, for bolts and screws having a thread major diameter of less than 0.75 inch and subject to removal for routine maintenance purposes shall be provided with steel inserts. Inserts shall not project above the mating surface. Wire wound inserts shall not be inserted more than 1.75 turns below the mating surface. All other types of inserts shall not be inserted more than one turn below the mating surface.

3.8 Materials and Finishes

3.8.1 Critical and Strategic Materials. Materials shall be selected on the basis of suitability and relative availability. Subject to satisfactory operation, the design shall incorporate the least critical and strategic materials.

3.8.2 Prohibitive Materials

3.8.2.1 Paints or organic finishes, epoxy, adhesives, foam or fiber materials and magnetic materials shall not be used in the design or construction of the unit.

3.8.2.2 Oils, greases, dry film lubricants, thread compounds or other types of materials which are applied and which over a period of time may cause contamination or may result in a gradual change in the characteristics of the unit shall not be used in the assembly or construction of the unit without approval from the Purchaser.

3.8.3 Finishes

3.8.3.1 Aluminum Alloys. Aluminum structural parts which do not need to be grounded or bonded shall be anodized in accordance with Specification MIL-A-8625 or equivalent or shall receive an approved chemical film in accordance with Specification MIL-C-5541. A two to five minute immersion in a solution containing 5 to 10 percent chromic acid in water, and maintained at 49° to 60°, may be used in lieu of anodizing or a chemical film in accordance with Specification MIL-C-5541 or parts fabricated from aluminum 2S, aluminum alloy 3S, 52S, 53S, 61S, 63S, 72S, or equally corrosive-resistant alloys.

3.8.3.2 Cadmium and Cadmium Plated Parts. Cadmium and cadmium plated parts shall not be used in the design and construction of either internal or external parts of the unit.

3.8.3.3 Ferrous Alloys. Corrosive resistant ferrous alloys shall be given a passivation treatment, but need not receive any other protective plating or finish unless such plating or finish is necessary or desirable for electrical or mechanical reasons. Straight chromium stainless steels shall not be required to receive passivation treatment if corrosion resistant requirements are met.

3.8.3.4 Magnesium and Magnesium Alloys - Magnesium alloys shall be finished in accordance with specification MIL-M-3171.

3.8.3.5 Zinc and Zinc Plated Parts. Zinc and zinc plated parts shall not be used in the design and construction of either internal or external parts of the unit.

3.8.4 "0" Rings. A sealed body and overall design (except for ports) which provides minimum use of "0" rings is preferred. The "0" rings shall be manufactured from a material for which a rubber cure date on the "0" ring will not be applicable.

3.9 Cleanliness. Prior to assembly each component part of the unit shall be thoroughly cleaned to remove grease, oil, chips, scale, etc., per General Electric Specification 118A1630. The rinsing or flushing solution shall be cleaned by passing the solution through a 5 micron or smaller rating filter. The parts shall be cleaned in this solution until the final rinse contains no more than the number of particles shown below per 100 ML of solution filtered through a standard HA millipore filter.

Particle Size	Maximum Number of Particles
10-20	120
20-40	80
40-80	20
80 and up	0

3.10 Stabilization of Non-Metallic Materials. For the purpose of stabilizing "0" rings, non-metallic diaphragms, non-metallic seats, etc., whose dimensions and/or characteristics are susceptable to change over the temperature range specified herein when under the stresses they will experience in service, subject parts shall be stabilized at a temperature of $155 \pm 5^{O}F$ for a period of at least 8 hours under simulated normal maximum stress conditions.

3.11 External Configuration

3.11.1 Mounting and port provisions and envelope shall be in accordance with the applicable General Electric drawing. Where holes or screw threads are provided for mounting the unit and for attachment of fittings, ample clearance shall be provided for installation and wrenching of the bolts, screws, nuts, fittings, etc.

3.11.2 The direction of flow or port identification shall be clearly and permanently indicated on the unit.

3.12 Weight. The weight shall be kept to a minimum and shall not exceed that specified on the applicable General Electric drawing.

3.13 Contamination and Filters

The unit shall meet all requirements specified herein without inlet or outlet filters when supplied with the operating fluid specified in paragraph 3.15.4. To guard against ingestion of contamination from sources other than the operating fluid proper, a filter shall be provided in the inlet and outlet ports unless authorized otherwise by the Purchaser. The filters shall not include bypassing provisions. The filter elements shall be of the woven wire type. The filter elements shall be suitably constructed and supported so as not to be damaged by transient flows up to 3.0 times the maximum flow specified herein. The micron size of the filter element shall be selected by the vendor as required to protect the unit except that the micron size shall not be less than that specified in paragraph 3.15.4 for the operating fluid.

3.13.1 Inlet. The filtering area shall be such as to result in a pressure drop consistent with the flow requirements specified herein. The filtering area shall be approved by the Purchaser.

3.13.2 Outlet. There shall be a free flow (unfiltered) path to permit escape of particles from the unit of up to .060 inch diameter. The free flow path shall present a torturous path for particles tending to enter into the unit from the downstream during no flow conditions. The filtering area shall be approved by the Purchaser.

3.14 Exposure of Non-Metallic Parts and Sliding Surfaces to High Vacuum. The number of non-metallic parts and sliding surfaces exposed to ambient pressure shall be kept to a minimum. Where such parts and surfaces are exposed to ambient pressure, passages to ambient shall be provided which present torturous paths to the movement of molecules out of areas containing such parts and surfaces in an attempt to avoid extreme high vacuum.

3.15 Detail Design Requirements.

3.15.1 Service Conditions, Transportation, and Storage. These conditions apply when the unit is not pressurized, but with the ports capped.

3.15.1.1 Humidity. Relative humidity up to 100% with conditions such that condensation takes place in the form of water or frost during transportation.

3.15.1.2 Ambient Pressure. Ambient pressure from sea level static pressure to 3.4 in. Hg absolute during air transportation.

3.15.1.3 Temperature. Ambient temperature from -35° to +160°F during transportation.

3.15.1.4 Vibration. Complex vibration, including sinusoidal and random noise in each of the three directions at 5 g's rms over the range of 5 to 50 cps and at 1.5 g's rms over a range of 50 to 300 cps during transportation.

3.15.1.5 Shock. Handling shocks as specified in Procedure VI of MIL-E-4970.

3.15.1.6 Storage Life. Storage for a period of up to two years. The storage environment will provide temperatures from 50°F to 100°F and relative humidities of less than 50%.

3.15.2 Service Conditions, Launch. These conditions apply when the unit is pressurized at the normal operating pressure and with the unit in the closed condition.

3.15.2.1 Ambient Pressure. Ambient pressure will vary from sea level static pressure to 10^{-9} mm Hg. Abs. with the pressure decreasing at a rate of up to 1 in. Hg. per second.

3.15.2.2 Temperature. The temperature of the mounting surface and ambient air will be between +50°F and +110°F. Radiation effects will be negligible.

3.15.2.3 Vibration. The vibration inputs to the mounting surface will consist of the following, both of which will not occur simultaneously. Duration of vibration will be 15 minutes.

3.15.2.3.1 Random Gaussian Vibration at 15 g's rms over a frequency range of 20 to 2000 cps in each of the three directions.

3.15.2.3.2 Sinusoidal Vibration at the values (zero to peak) given below over the range of 10 to 3000 cps in each direction.

Frequency	Amplitude
10 to 50 cps	2.0 g
50 to 100 cps	8.0 g
100 to 250 cps	24.0 g
250 to 500 cps	8.0 g
500 to 2000 cps	16.0 g
2000 to 3000 cps	30.0 g

3.15.2.4 Acceleration. Acceleration of 18.5 g's in each direction along each of the three mutually perpendicular axes for a period of 4.5 minutes.

3.15.3 Service Conditions, Orbit. These conditions apply over the mission life of the unit as specified herein.

3.15.3.1 Ambient Pressure. Ambient pressure of 10^{-9} mm Hg.

3.15.3.2 Temperature. Ambient temperature of the mounting surface and inlet gas temperature will be +40 to +140°F.

3.15.3.3 Radiation. Radiation exposure of 0.3 roentgens per hour for a three month period.

3.15.3.4 Life. This mission life is 3 months during which time the following shall be considered to apply.

3.15.3.4.1 The unit may be cycled 500 times for charging and dumping the gas storage tanks.

3.15.3.4.2 The flow time per energized actuation is from several seconds to 5 hours for flow from the outlet to the inlet at rates up to 6 SCFM for charging and from several seconds to that required to deplete a 0.5 to 3 cubic foot tank from 2500 psig to 0 psig with the systems defined in 3.15.5.

3.15.3.4.3 The time between actuations of the unit will be from once per 10 minutes to once per month.

3.15.4 Operating Fluid. The operating fluid will be hydrogen or oxygen gas, dried to a dew point of $-65^{o}F$, with an oil contamination of less than 10 parts per million and a sediment contamination less than 25 parts per million, with 98% of the particles having a diameter less than 5 microns with 100% having a diameter less than 12 microns.

3.15.5 System Definition. The unit must meet the requirements of this specification when used in a system consisting of the following: Charge/dump connector (0.125" ESEOD) 2 feet of 0.25" O.D. by 0.020" wall tubing subject unit, 4 feet of 0.25"O.D. by 0.020" wall tubing and gas storage tank.

3.15.6 Operating Pressure. Inlet and outlet pressure will range from 0 to 3000 to 0 psig. The rate of pressure change may be up to 3000 psi per second.

3.15.7 Proof Pressure. The function of the unit shall not be impaired by operation with a pressure of 3750 psig applied to the inlet port or to the outlet port with the unit in the open or closed condition.

3.15.8 Burst Pressure. The unit shall be capable of withstanding a pressure of 6250 psig applied to the inlet or outlet port without rupture of internal or external parts.

3.15.9 Sustained Pressure. The function of the unit shall not be impaired by having the unit supplied with proof pressure at the inlet for 3 months at a vacuum level of 10^{-9} mm Hg Absolute with the unit closed and the outlet port exposed to ambient pressure of 10^{-9} mm Hg. Absolute.

3.15.10 Reliability. The unit shall be designed such that each unit delivered will have a reliability of 0.999 for meeting the requirements specified herein.

3.15.11 Radio Interference and Susceptability. The unit must operate within the radio interference limits per MIL-I-26600.

3.16 Performance Requirements

3.16.1 Pressure Drop. The unit shall not exhibit a pressure drop in excess of 2500 psi in either direction with a flow rate of 20 SCFM of nitrogen with the low pressure port at ambient pressure.

3.16.2 Leakage.

3.16.2.1 External. The total external leakage shall not exceed 2 SCC per hour at any pressures up to the proof pressures with the unit in the open or closed condition.

3.16.2.2 Internal Leakage. The total internal leakage through the outlet port shall not exceed 2 SCC per hour with any inlet pressure up to the proof pressure and any differential pressure from 0 psi to the proof pressure. The total internal leakage through the inlet port shall not exceed 2 SCC/Hr. with any outlet pressure up to the proof pressure and any differential pressure from 0 psi to 1000 psi. The unit need not seal at differential pressures above 1000 psi applied in the oulet to inlet direction.

3.16.3 Operating Voltage. The unit shall operate properly over the voltage range from 18 to 34 VDC, 28 VDC nóminal, with a maximum voltage of 3 VDC applied in the non-energized condition.

3.16.4 Power. The unit shall not require more than 36 watts at 28 VDC at 70°F.

3.16.5 Resistance to Ground. The resistance between each pin of the electrical connector and the case shall be at least 50 megohms at 500 VDC.

3.16.6 Response Time. The unit shall go from the closed to the full open condition within 1.0 seconds after application of an 18 VDC signal. The unit shall go from the open to the full closed condition within 1.0 seconds after reducing the voltage below 3 volts.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Test Responsibility. The vendor shall and the purchaser will conduct tests on completed units to ascertain that the units meet the requirements of this specification.

4.1.1 Tests shall be conducted by the vendor in accordance with any QAP (Quality Assurance Provision) or other test requirements that are referenced on the purchase order for the units.

4.1.2 Performance tests shall be conducted by the vendor in accordance with paragraph 4.4.1. A data sheet shall be provided with each unit showing its performance.

4.1.3 The vendor should conduct any additional tests that he deems necessary to ascertain that the unit will meet the requirements of this specification.

4.1.4 Additional testing will be conducted by the General Electric Company as specified in Section 4 of this specification. This testing may repeat any or all tests performed by the vendor and may include tests in addition to those specifically called for in Section 4 to verify design requirements of the unit delineated in Section 3 of this specification.

4.2 Test Accuracy, Conditions, and Reports

4.2.1 Test Accuracy. All pressure, temperature, electrical, air flow, etc. measurements specified in this specification are true values. Assuming that it were possible to set, control, measure and read all test parameters to the exact true value, the exact characteristics and performance would be determined. Since this is not possible, however, it is required that the cumulative effect of all instrumentation and control inaccuracies plus possible setting and reading errors shall not result in a difference of more than plus or minus four percent between the true values and recorded values.

4.2.2 Test Conditions. The vendor shall agree to the establishment of accepted test procedures and test conditions so that the development, qualification and production quality control shall be most efficiently accomplished. The establishment of test conditions shall be at the recommendation of the vendor and the approval of the purchaser. A 5 micron nominal, 12 micron absolute filter shall be used immediately upstream of the unit. All tests shall be conducted in chronological order as given herein. Nitrogen or helium gas shall be used unless otherwise specified. Helium shall be used for the Functional Leakage Tests; the leakage limits given herein shall apply when using helium.

4.2.3 Test Conditions. Unless otherwise specified, Functional Tests shall be conducted under the following conditions:

(a) Temperature, $25^{\circ}C \pm 10^{\circ}C$.

(b) Relative Humidity, 90% or less.

(c) Barometric Pressure, 28 to 32 inches of mercury.

4.2.4 Chamber Volume. The unit being tested plus associated test equipment shall not exceed 50% of the internal volume of the test chamber.

4.2.5 Temperature Definition. For temperature tests at pressures greater than 10^{-1}mm Hg, the temperature referred to is ambient air temperature. In these tests the heat sources shall be such that radiant heat is not directed on the unit. For temperature tests under vacuum, pressure less than 10^{-4} mm Hg, temperatures are the mounting surface temperature.

4.2.6 Temperature Tests. During perfom ance testing under temperature environmental conditions the entire system, including a gas supply reservoir, shall be placed in the temperature chamber and the gas temperature is to be within $\pm$ 3°F of the environmental temperature. Expansion and escape of entrapped gas within the test hardware is not to be misconstrued as leakage. Any escapement shall cease after temperature stabilization.

4.2.7 Rejection and Retest. When a unit fails to meet the specification, acceptance of any additional units shall be withheld until the extent and cause of failure has been determined. After required corrections or changes have been made, all necessary tests shall be performed again. Acceptance of additional units will be resumed when 3 additional units have successfully passed the tests which resulted in initial failure. A failure report shall be prepared on each failure.

4.3 Classification of Tests. The unit shall be submitted to the following classes of tests.

4.3.1 Functional Tests. Tests conducted to determine that each unit operates satisfactorily within the performance specified in this specification at sea level static conditions. These tests are defined in paragraph 4.4.1 and are to be conducted on units in accordance with the following:

4.3.1.1 After final assembly of each unit and prior to shipment to the purchaser, or after any repair or modification of a unit. If the performance at conditions other than the Test Conditions stated in paragraph 4.2.3 differs notably from that at the conditions per paragraph 4.2.3, the acceptable performance applicable at these conditions shall be restricted so as to assure that the performance of the unit will be satisfactory at all other conditions required by this specification.

4.3.1.2 During Acceptance and Qualification Testing as specified in paragraphs 4.4.2 and 4.4.3.

4.3.2 Quality Assurance Tests. Tests conducted at the discretion of the purchaser at simulated flight environments to determine that the integrity of units is continually such as to be suitable for flight. These tests are defined in paragraph 4.4.2 and will be conducted by the Purchaser. Failure of the unit to successfully complete these tests will be cause for rejection per paragraph 4.2.7.

4.3.3 Qualification Tests. Tests conducted at simulated flight environments to acquire assurance that the unit is capable of performing satisfactorily and reliably for the duration of the intended service life as defined herein. These tests are defined in paragraph 4.4.3. At its option, the Purchaser may select units built to production drawings to be subjected to the Qualification Tests specified herein and performed either by the purchaser or by the vendor on a supplementary order to establish conformance with this specification. If units are shipped to the purchaser prior to successful completion of these tests, the vendor will be financially responsible for modifying the units shipped with such changes as may be required to acquire successful completion of these tests. Throughout these tests the performance of the unit shall be within the performance specified in this specification. If and as failures occur on the initial qualification attempt, the unit shall be repaired and the test continued on this unit until the unit has completed all tests. The failures shall be analyzed and improvements incorporated into the unit to be used for the second qualification attempt. Failure of the unit to successfully complete these tests will be cause for rejection per paragraph 4.2.7.

4.4 Test Methods. 28 VDC power shall be supplied to the unit except as otherwise specified.

4.4.1 Functional Tests.

4.4.1.1 Physical Examination. Each unit shall be examined to determine conformance with this specification, with the applicable General Electric Drawing and with regard to material, workmanship, construction and marking.

4.4.1.2 Proof Pressure. With the outlet port capped and the unit de-energized apply the proof pressure to the inlet port. Open and close the unit. Note any gas leakage or high pressure effects for one minute.

4.4.1.3 Static Leakage

4.4.1.3.1 External. With the outlet capped and the unit open apply the proof pressure to the inlet port and measure external leakage.

4.4.1.3.2 Internal. Energize the unit briefly with 34 VDC and lower the voltage to 3 volts. With the 3 volts applied and the outlet port open apply the proof pressure to the inlet port. Measure the total, internal and external, leakage. Repeat with the inlet port capped and the outlet port pressurized to 1000 psig. Repeat the test with 200 psig pressure.

4.4.1.4 Pull In and Drop Out Voltage. With the unit open apply the normal operating pressure to the inlet and exhaust the gas via a restriction which results in the outlet pressure from the unit being 85 to 95% of the inlet pressure. With the unit closed increase the applied voltage slowly to determine the voltage at which the outlet pressure is 10% less than that recorded at the open condition. Decrease the voltage slowly until the outlet pressure is 3% of the normal operating pressure. Repeat this procedure at an inlet pressure of 10% of the normal operating pressure. Repeat this procedure pressurizing the outlet port to 1000 psig and exhausting via the inlet port.

4.4.1.5 Pressure Drop. With the unit closed and installed in the system as defined in paragraph 3.17.5, supply an inlet pressure of 2500 psig. Open the unit and measure the flow with nitrogen gas. Repeat this procedure except pressurizing the outlet port with 1000 psig. The unpressurized port shall be exhausted to ambient via the specified tubing. In lieu of this method, the time to bleed a given amount of gas may be used.

4.4.1.6 Electrical Power. The resistance between coil winding pins in the electrical connector shall not be less than 22 ohms.

4.4.1.7 Insulation Resistance. The resistance between each pin in the electrical connector and the case shall be measured with 500 VDC applied.

4.4.1.8 High Potential Test. The vendor shall conduct a high potential test by applying 500 volts, rms at 60 cps (500 VDC may be used) between each coil winding pin in the electrical connector and the case for a period of one minute. There shall be no evidence of mechanical or electrical failure. The test shall be conducted in accordance with MIL-STD-202. The test shall not be repeated by the Purchaser except at the conclusion of Qualification Testing.

4.4.2 Quality Assurance Tests. The Functional Tests of paragraph 4.4.1 shall precede and follow this series of tests. No deterioration in performance is permissible during these tests. Performance at all conditions must be within design limits as specified herein.

4.4.2.1 Vibration Test.

4.4.2.1.1 Shaker-Fixture Unit Resonance Test. Prior to performing the vibration test, if an identical unit and an identical fixture have not been previously vibrated in the machine to be employed for the vibration test, one unit shall be subjected to vibration in each of its three mutually perpendicular axes through the frequency range of from 10 to 3000 cps. If any alterations are made in the machine, fixture, or unit, or if a different machine or fixture is employed, this test shall be repeated. The unit shall be attached to the test fixture through the attachment points in such a manner as to provide no additional stiffness or restraint other than at the attachment points. The vibration response shall be monitored through the entire frequency range in three mutually perpendicular directions at each attachment point of the unit to the fixture. The amplitude readings normal to the direction of excitation shall be no greater than 50% of the maximum level in the direction of excitation. The maximum and minimum amplitude readings taken in the direction of shake at the attachment points shall not differ from each other by more than 50%.

The unit-fixture-table combination shall be altered until these conditions are satisfied. The frequency sweep shall be manually controlled to insure that all resonances observed at the attachment points are fully excited. Resonant frequencies, bandwidth, and amplification of all resonances shall be noted and recorded. The vibration amplitude

shall be varied with frequency such that the amplitude at the attachment points is as follows:

Frequency	Amplitude
5 to 20 cps	0.2 inches peak to peak
20 to 3000 cps	2 g's

4.4.2.1.2 Sinusoidal Vibration. The unit shall be subjected to sinusoidal vibration along each of its three mutually perpendicular axes with the amplitudes as specified in paragraph 3.15.2.3.2. The sinusoidal vibration shall be swept once at approximately two octaves per minute During this test, the unit shall be closed and pressurized to the 3000 psig at the inlet port and the leakage shall be monitored with the outlet port vented to ambient.

4.4.2.1.3 Random Vibration. Random Gaussian vibration shall be applied to the unit for a period of 10 minutes over a frequency range of 20 to 2000 cps at 15 g's rms along each of its three mutually perpendicular axes. During this test the unit shall be closed and pressurized to 3000 psig at the inlet port and the leakage shall be monitored with the outlet port vented to ambient.

4.4.2.2 Endurance Test. With the unit closed and installed in the system as described in paragraph 3.15.5, with a tank of 0.50 ± 0.05 ft^3 volume increase the pressure to the outlet port slowly while cycling the unit open and closed while charging the tank to 3000 psig. The unit shall be cycled 100 times such as to cycle the unit at approximately every 30 psi increase in pressure. After having charged the tank to 3000 psig, vent through the outlet to ambient cycling the unit open and close at approximately every 100 psi decrease in tank pressure.

4.4.2.3 High Temperature Test. The unit shall be placed in a test chamber and 3000 psig applied to the inlet port with the unit closed and the outlet port vented to ambient. The ambient pressure shall be reduced to less than 0.25 psia. The temperature of the unit and the gas shall be raised to 140°F while maintaining the 3000 psig inlet pressure. The pressure shall then be cycled 3 times at a rate of 1 cycle per approximately 2 hours from 3000 to 0 psig while monitoring leakage. The pressure shall be decreased slowly from 3000 psig to 0 psig over a period of approximately 110 minutes with the remaining time used to recharge the pressure.

4.4.2.4 Low Temperature Test. This test shall be performed as in paragraph 4.4.2.3 except using a temperature of 40°F.

4.4.3 Qualification Tests.

4.4.3.1 Function and Environment Qualification. The following tests shall be performed on a single unit. The unit shall have passed the Quality Assurance Tests prior to being subjected to this test and shall pass the Quality Assurance Tests (except for vibration which shall not be done) upon completion of these tests. Prior to and after the tests of each sub-paragraph of this paragraph, i.e., 4.4.3.1.1, 4.4.3.1.2, etc., the unit shall be subjected to and pass the Functional Tests of paragraph 4.4.1 except the tests of 4.4.1.2, 4.4.1.5 and 4.4.1.7 shall be performed on the last Functional Test only. Performance must be within design limits as established herein throughout all tests. No adjustment or disassembly whatsoever is permissible except for the teardown inspection after the test.

4.4.3.1.1 Transportation and Storage Tests.

4.4.3.1.1.1 While non-pressurized and with shipping plugs loosely installed in the ports, the unit shall be subjected to an ambient temperature of -35°F and shortly thereafter to an ambient pressure of 87.5 mm Hg. Abs. These conditions shall be maintained for 8 hours at which time the pressure shall be returned to atmospheric and subsequently the temperature shall be returned to room temperature. The rate of pressure change shall not exceed 200 mm Hg. per minute.

4.4.3.1.1.2 While non-pressurized the unit shall be subjected to an ambient temperature of +160 °F with a relative humidity of less than 5% for 8 hours at which time atmospheric conditions shall be restored.

4.4.3.1.1.3 While non-pressurized and with shipping plugs loosely installed in the ports, the unit shall be subjected to a temperature of 120°F and a relative humidity of at least 95% for a period of 24 hours. Distilled or demineralized water having a ph value of between 6.5 and 7.5 at 25°C (77°F) shall be used to obtain the desired humidity. The velocity of the air within the chamber shall not exceed 150 ft/min

4.4.3.1.2 Pre-Launch and Launch Tests.

4.4.3.1.2.1 System Charging Test. With the inlet system terminating into a 0.50 $\pm$ 0.05 ft^3 tank open the unit and increase the outlet pressure gradually

to 3000 psig maintaining a differential pressure from the outlet to the inlet of 100 ± 10 psi. Read the pressures periodically as a function of time. Close and open the unit at tank pressures of 1000, 2000 and 3000 psig long enough to observe that the unit is closing and opening.

4.4.3.1.2.2 System Dumping Test. With the system as defined in paragraph 3.15.5 with a 0.50 ± 0.05 ft^3 tank charged to 3000 psig open the unit and permit gas to flow to ambient. Close and open the unit at 2000 and 1000 psig to observe that the unit is closing and opening. Record the pressures. Read the pressures periodically as a function of time.

4.4.3.1.2.3 Vibration Test. This will have been accomplished in the Quality Assurance Test.

4.4.3.1.2.4 Acceleration Test. The unit shall be exposed to a steady state acceleration of 18.5 g's for a period of not less than 4.5 minutes in both directions along the three mutually perpendicular axes. During this test, the inlet shall be closed and pressurized to 3000 psig and the leakage monitored with the outlet port vented to ambient pressure.

4.4.3.1.2.5 Shock Test. The unit shall be subjected to three 30 g shocks in each direction along the three mutually perpendicular axes for a total of 18 shocks. Time to peak of each shock shall be 6 ms. Duration of each shock shall be 12 ms. The shock intensity shall be within 10% of 30g when measured with a filter having a bandwidth of 0 to 800 cps. The unit shall not be pressurized during this test. Duration of the pulse shall be that interval of time beginning when the amplitude first has a value which is 10% of the peak g and extending to the instant when the amplitude is again 10% of the peak value. Insofar as is possible the fixture to support the unit shall be free of resonance in the frequency range of 0 to 1000 cps.

4.4.3.1.3 Ornit Tests.

4.4.3.1.3.1 Thermal Vacuum Test. The unit shall be placed in a test chamber and the 3000 psig applied to the inlet port with the unit closed and the outlet port vented to ambient pressure. A minimum distance of three inches between components and the chamber wall and between the test component and other components shall be maintained. The ambient pressure shall be reduced to 1×10^{-6} mm Hg. The inlet gas supply shall be from a 14 ± 3 in^3 container. Monitor internal and external

leakage throughout the test. While at this ambient pressure the following thermal vacuum test schedule shall be followed:

(a) With an inlet pressure of 3000 psig for 24 hours at room temperature.

(b) With an inlet pressure of 2500 psig for 24 hours increasing the temperature to +150°F during the last 8 hours.

(c) Repeat "a" at the 150°F temp. and 2000 psig.

(d) Repeat "b" at 1500 psig reducing the temperature to +30°F during the last 8 hours.

(e) Repeat "a" at the 30°F temp. and 1000 psig.

(f) Repeat "b" at 500 psig increasing the temp. to room temp. during the last 8 hours.

(g) Repeat "a" at 200 psig at room temperature.

5. PREPARATION AND DELIVERY

5.1 Preservation. All ports shall be suitably protected to exclude foreign matter in such a way that the unit cannot be assembled into a system without removal of the protective cover. Threaded parts shall be protected with a threaded type cap or plug. Covers used to protect flange type pads shall cover the entire pad surface including all threaded holes and other openings not used to retain the cover.

5.2 Interior Packages.

5.2.1 Packaging. The component shall be sealed in a polyethylene or nylon bag of a thickness of at least 5 mills. The component and bag shall be enclosed in a container which provides protection of the component during shipment and handling. The ports of the component shall be closed with one of the following:

1. GEON 121 Polyvinyl chloride caps or similar plastic as specifically approved by GE/MSD. Polyethylene caps are specifically prohibited.

2. Nylon tape or 5 mill minimum polyethylene film over the ports, provided the tape is not applied to the thread.

All packaging material in contact with the component shall be cleaned to the same level as specified in paragraph 3.9 herein.

5.2.2 Each interior package shall be durably and legibly marked with the following information where applicable in such a manner that the markings will not become damaged when the packages are opened.

(a) Name of the unit,

(b) Purchaser's order number,

(c) Vendor's name ,

(d) Serial Number,

(e) General Electric part number,

(f) Cleaning information per 118A1630.

5.3 <u>Exterior Packages</u>.

5.3.1 Packaging and Packing. Unless otherwise specified, the interior packages shall be packed in a substantial commercial exterior shipping container constructed to insure acceptance by common or other carrier for safe transportation at the lowest rate to the point of delivery.

5.3.2 Marking. The exterior shipping container shall be marked in accordance with MIL-STD-129.

5.4 Transportation. The unit shall be packaged for shipment in such a manner as to withstand, without physical or functional damage, conditions as encountered in domestic shipment in accordance with commercial procedures. To avoid temperature below -35°F during air travel, the shipment shall be marked "Restricted Air Transportation."

Specification No.: SVS 7054
Date: August 1962

General Electric Company
Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555
Philadelphia 1, Pennsylvania

COMPONENT SPECIFICATION FOR A

REGULATOR, PNEUMATIC-PRESSURE

Prepared by: /s/ H. P. Marderness Date: October 17, 1962
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Approved by: Date:
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Specification No.: SVS 7054
Date: August 1962

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REGULATOR, PNEUMATIC-PRESSURE

1. SCOPE

1.1 General. This specification establishes the design, fabrication and test requirements for a satellite pneumatic pressure regulator, hereinafter referred to as the unit. This unit will be employed in a sub-system for the purpose of controlling gas flow upon demand at a regulated pressure and providing a lock-up condition when no flow demand exists.

1.1.1 The requirements of this specification are detailed only to the extent considered necessary to obtain desired performance and reliability.

1.1.2 The following classes of the unit are described herein:

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1.1.3 Neither the acceptance by the Purchaser of the unit(s) specified herein or of any of the data specified by this detail requirement and others forming part of this specification nor any review or approval by the Purchaser of Vendor drawings or other documents nor the acceptance by the Vendor of design recommendations made by the Purchaser, shall be construed as releasing or, modifying in any way the Vendor's responsibility to meet all the requirements of this specification.

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2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of initiation for bids, form a part of this specification.

Military Specifications

MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys.
MIL-C-5541	Chemical Films for Aluminum and Alumnium Alloys.
MIL-D-70327	Drawings, Engineering and Associated Lists.
MIL-E-4970	Environmental Testing, Ground Support Equipment.
MIL-I-26600	Radio Interference.
MIL-M-3171	Magnesium Alloy, Processes for Corrosion - Protection of.
MIL-Q-9858	Quality Control System Requirements.

General Electric Specifications

118A1526	Identification Marking.
118A1630	Oxygen System Components, Cleanliness - Control for.

Military Standards

MIL-STD-129	Marking for Shipment and Storage.
MIL-STD-202	Test Methods for Electronic Component Parts.
MS 33540	Safety Wiring, General Practices for.
MS 33588	Nuts and Plate Nuts, Self-Locking.
AND 20995	Wire, Lock.

Military Handbooks

H-28 Screw Thread Standards for Federal Services.

2.2 Precedence. In the event of conflict between the Purchase Order, this Specification or subsidiary Specifications, the order of precedence shall be as follows:

1st - Purchase Order.

2nd - This Specification.

3rd - Subsidiary Specifications (all Specifications referenced herein).

3. REQUIREMENTS

3.1 Identification of Unit. Identification and serializing of units shall be in accordance with General Electric Specification 118A1526 and in the location shown on the applicable General Electric drawing. Nameplates shall be attached with threaded fasteners and lockwired against loosening or falling off.

All other methods of attachment shall be prohibited except for the following:

(a) Threaded screws with nylon locking devices may be used.

(b) Rivets may be used in special cases only; such as on sheet metal shields, covers, or boxes. Where used, the upset end of the rivet shall be on the identification surface of the nameplate so that faulty workmanship may be inspected and so that attachment may be recognized.

3.2 Consistency and Identification of Design

3.2.1 Interchangeability. All parts or combination of parts (subassemblies) having the same manufacturer's number shall be directly and completely interchangeable with each other with respect to safety, durability, weight, installation, spare parts and performance. Changes in manufacturer's part numbers shall be subject to approval by the

Purchaser as specified in Paragraph 3.2.2 and shall be governed by the drawing requirements of Specification MIL-D-70327.

3.2.2 Change in Design. No changes shall be maue in the design, material, process, sub-vendors or construction of the unit from the model which has been approved and released by the Purchaser, except when such changes are approved by the following methods:

(a) Any change affecting weight, interchangeability, process, performance, durability, safety, material, spare parts, model or assembly number, sub-vendors (including the vendor's facility), any specification control drawing requirements, cost or delivery dates shall be accompanied with official substantiation of qualification test data and drawings clearly illustrating the proposed change. Approval by the Purchaser is required prior to introduction of all such changes. Upon approval of these changes by the Purchaser of the parts affected engineering data shall be furnished in accordance with Paragraph 3.5.

Model or assembly number changes shall be made in conformance with Specification MIL-D-70327.

(b) Changes not restricted by Paragraph 3.2.2(a) may be adopted by the vendor. Upon adoption of such changes, engineering data shall be furnished as specified in Paragraph 3.5 Final acceptance of each unit will be at the discretion of the Purchaser upon review of the data to be provided with each unit as specified in Paragraph 3.5.2.

3.3 Workmanship. The unit shall be manufactured, assembled and tested in a thoroughly workmanlike manner. Particular attention shall be given, as applicable, to neatness and thoroughness of manufacture of parts, assembly, sub-assembly inspections, final assembly and inspection and final assembly tests. In general the quality control requirements shall conform to applicable portions of MIL-Q-9858.

3.4 Productiveness. The unit shall be designed for optimum employment of mass production techniques consistent with the requirements of this specification; particularly with regard to non-susceptability of reliability of the unit to manufacturing, assembly and test techniques.

3.5 Drawings and Data List. The vendor shall supply the purchaser with the following material and information; the cost of which shall not be included in the price of the units, but shall be costed separately.

3.5.1 The following shall be supplied within not less than 30 days prior to delivery of the first unit.

3.5.1.1 A complete set of reproducible copies of drawings (assembly, sub-assembly, and detail), parts list, provisioning parts breakdown list, material specification, heat treat and finish specifications and the supplier of each part and process.

3.5.1.2 A list of all detail parts which require selective assembly.

3.5.1.3 A list of critical and/or strategic materials used.

3.5.1.4 A list and description of any special tools required for disassembly, reassembly, and adjustment. The number of these items shall be kept to a minimum.

3.5.1.5 A report showing the performance and effects thereon of range in tolerances, temperatures, pressures, flow, transients, etc.

3.5.1.6 An inspection procedure manual. List of all sub-assembly tests planned to acquire assurance, during buildup of the unit, that the design intent exists in each unit; i.e., force margins, leakages, etc., and tests conducted on the completed unit.

3.5.1.7 A manual showing assembly and test procedures.

3.5.2 Each unit when delivered shall be accompanied by a detailed inspection record for the unit giving the information specified in 3.5.1.6. There shall have been 100% inspection of all parts, sub-assemblies

and the complete assembly with regard to all characteristics except for characteristics that would require destructive testing. In general, no deviation will be accepted. Any deviations existing shall be tabulated in a separate listing. Only authorized General Electric Company, MSD personnel may approve any deviation.

3.5.3 On a monthly basis a report shall be supplied with a tabulation relating the number of units sent to test, the number of failures (normal adjustments are not to be considered failures), the nature of the malfunction, the corrective action taken, the number of units that failed in the second time to test, etc., accounting for each unit that was sent to test.

3.6 Securing of Threaded Parts and Adjustments

3.6.1 All internal or externally located nuts, screws, caps, plugs, or ıer movable parts shall be either positively locked or safety wired in accordance with MS33540 and drawing AND20995, or other means approved by the purchaser.

3.6.2 When a seal is used to provide security against tampering with, or unauthorized adjustment, of the unit, the seal shall be made of a light-weight, non-corrosive material such as aluminum and preferably shall be of a tubular configuration. Lead seals shall not be used. The seal shall be secured in such a manner that under no circumstances will the seal break loose. It shall be located between secured elements rather than after the last lock-wired element.

3.7 Screw Threads

3.7.1 Threads shall be in conformance with Handbook H-28. No tapered pipe threads shall be used.

3.7.2 Self-Locking Nuts. If self-locking nuts are used, they shall be made by an approved Vendor. The use of self-locking nuts shall be in accordance with requirements of MS33588, paragraphs 1 and 2 and 5 through 8. Bolts shall extend through nuts at least the full chamfer plus one and one-half pitches.

3.7.3 Inserts. Threads in "soft" metals, i.e., aluminum alloys, for bolts and screws having a thread major diameter of less than 0.75 inch and subject to removal for routine maintenance purposes shall

be provided with steel inserts. All mating and mounting threaded bolt holes in these "soft" metals shall be provided with steel inserts. Inserts shall not project above the mating surface. Wire wound inserts shall not be inserted more than 1.75 turns below the mating surface. All other types of inserts shall not be inserted more than one turn below the mating surface.

3.8 Materials and Finishes

3.8.1 Critical and Strategic Materials. Materials shall be selected on the basis of suitability and relative availability. Subject to satisfactory operation, the design shall incorporate the least critical and strategic materials.

3.8.2 Prohibitive Materials

3.8.2.1 Paints or organic finishes, epoxy, adhesives, foam or fiber materials and magnetic materials shall not be used in the design or construction of the unit.

3.8.2.2 Oils, greases, dry film lubricants, thread compounds or other types of materials which are applied and which over a period of time may cause contamination or may result in a gradual change in the characteristics of the unit shall not be used in the assembly or construction of the unit without approval from the Purchaser.

3.8.3 Finishes

3.8.3.1 Aluminum Alloys. Aluminum structural parts which do not need to be grounded or bonded shall be anodized in accordance with Specification MIL-A-8625 or equivalent or shall receive an approved chemical film in accordance with Specification MIL-C-5541. A two to five minute immersion in a solution containing 5 to 10 percent chromic acid in water, and maintained at 49° to 60°, may be used in lieu of anodizing or a chemical film in accordance with Specification MIL-C-5541 or parts fabricated from aluminum 2S, aluminum alloy 3S, 52S, 53S, 61S, 63S, 72S, or equally corrosive-resistant alloys.

3.8.3.2 Cadmium and Cadmium Plated Parts. Cadmium and cadmium plated parts shall not be used in the design and construction of either internal or external parts of the unit.

3.8.3.3 Ferrous Alloys. Corrosive resistant ferrous alloys shall be given a passivation treatment, but need not receive any other protective plating or finish unless such plating or finish is necessary or desirable for electrical or mechanical reasons. Straight chromium stainless steels shall not be required to receive passivation treatment if corrosion resistant requirements are met.

3.8.3.4 Magnesium and Magnesium Alloys. Magnesium alloys shall be finished in accordance with specification MIL-M-3171.

3.8.3.5 Zinc and Zinc Plated Parts. Zinc and zinc plated parts shall not be used in the design and construction of either internal or external parts of the unit.

3.8.4 "0" Rings. A sealed body and overall design (except for ports) which provides minimum use of "0" rings is preferred. The "0" rings shall be manufactured from a material for which a rubber cure date on the "0" ring will not be applicable.

3.9 Cleanliness. Prior to assembly each component part of the unit shall be thoroughly cleaned to remove grease, oil, chips, scale, etc., per General Electric Specification 118A1630. The rinsing or flushing solution shall be cleaned by passing the solution through a 5 micron or smaller rating filter. The parts shall be cleaned in this solution until the final rinse contains no more than the number of particles shown below per 100 ML of solution filtered through a standard HA millipore filter:

Particle Size	Maximum Number of Particles
10-20	120
20-40	80
40-80	20
80 and up	0

3.10 Stabilization of Non-Metallic Materials. For the purpose of stabilizing "0" rings, non-metallic diaphragms, non-metallic seats, etc., whose dimensions and/or characteristics are susceptable to change over the temperature range specified herein when under the stresses they will experience in service, subject parts shall be stabilized at a temperature of 155 $\pm$ 5 ^{o}F for a period of at least eight hours under simulated normal maximum stress conditions.

3.11 External Configuration

3.11.1 Mounting and port provisions and envelope shall be in accordance with the applicable General Electric drawing. Where holes or screw threads are provided for mounting the unit and for attachment of fittings, ample clearance shall be provided for installation and wrenching of the bolts, screws, nuts, fittings, etc.

3.11.2 The direction of flow or port identification shall be clearly and permanently indicated on the unit.

3.12 Weight. The weight shall be kept to a minimum and shall not exceed that specified on the applicable General Electric drawing.

3.13 Contamination and Filters. The unit shall meet all requirements specified herein without inlet or outlet filters when supplied with the operating fluid specified in paragraph 3.15.4. To guard against ingestion of contamination from sources other than the operating fluid proper, a filter shall be provided in the inlet and outlet ports unless authorized otherwise by the Purchaser. The filter shall not include by-passing provisions. The filter elements shall be of the woven wire-type. The filter elements shall be suitably constructed and supported so as not to be damaged by transient flows up to 3.0 times the maximum flow specified herein. The micron size of the filter element shall be selected by the vendor as required to protect the unit except that the micron size shall not be less than that specified in paragraphs 3.15.4 for the operating fluid.

3.13.1 Inlet. The filtering area shall be such as to result in a pressure drop of less than 0.5 psi with twice maximum flow at the normal operating pressure. The filtering area shall be approved by the purchaser.

3.13.2 Outlet. There shall be a free flow (unfiltered) path to permit escape of particles from the unit of up to .060 inch diameter. The free flow path shall present a torturous path for particles tending to enter into the unit from the downstream during no flow conditions. The filtering area shall be approved by the Purchaser.

3.14 Exposure of Non-Metallic Parts and Sliding Surfaces to High Vacuum. The number of non-metallic parts and sliding surfaces exposed to ambient pressure shall be kept to a minimum. Where such parts and surfaces are exposed to ambient pressure, passages to ambient shall be provided which present torturous paths to the movement of molecules out of areas containing such parts and surfaces in an attempt to avoid extreme high vacuum.

3.15 Detail Design Requirements

3.15.1 Service Conditions, Transportation, and Storage. These conditions apply when the unit is not pressurized, but with the ports capped.

3.15.1.1 Humidity. Relative humidity up to 100% with conditions such that condensation takes place in the form of water or frost during transportation.

3.15.1.2 Ambient Pressure. Ambient pressure from sea level static pressure to 3.4 in. Hg absolute during air transportation.

3.15.1.3 Temperature. Ambient temperature from -35° to $+160^{\circ}$F during transportation.

3.15.1.4 Vibration. Complex vibration, including sinusoidal and random noise in each of the three directions at 5 g's rms over the range of 5 to 50 cps and at 1.5 g's rms over a range of 50 to 300 cps during transportation.

3.15.1.5 Shock. Handling shocks as specified in Procedure VI of MIL-E-4970.

3.15.1.6 Storage Life. Storage for a period of up to two years. The storage environment will provide temperatures from 50°F to 100°F and relative humidities of less than 50%.

3.15.2 Service Conditions, Launch. These conditions apply when the unit is pressurized at 3000 psig and with a lockup or flow condition.

3.15.2.1 Ambient Pressure. Ambient pressure will vary from sea level static pressure to 10^{-9} mm Hg. Abs. with the pressure decreasing at a rate of up to 1 in. Hg. per second.

3.15.2.2 Temperature. The temperature of the mounting surface and ambient air will be between $+50^{o}F$ and $+110^{o}F$. Radiation effects will be negligible.

3.15.2.3 Vibration. The vibration inputs to the mounting surface will consist of the following, both of which will not occur simultaneously. Duration of vibration will be 15 minutes.

3.15.2.3.1 Random Gaussian Vibration at 15 g's rms over a frequency range of 20 to 2000 cps in each of the three directions.

3.15.2.3.2 Sinusoidal Vibration at the values (zero to peak) given below over the range of 10 to 3000 cps in each direction:

Frequency	Amplitude
10 to 50 cps	2.0 g
50 to 100 cps	8.0 g
100 to 250 cps	24.0 g
250 to 500 cps	8.0 g
500 to 2000 cps	16.0 g
2000 to 3000 cps	30.0 g

3.15.2.4 Acceleration. Acceleration of 18.5 g's in each direction along each of the three mutually perpendicular axes for a period of 4.5 minutes.

3.15.3 Service Conditions, Orbit. These conditions apply over the mission life of the unit as specified herein.

3.15.3.1 Ambient Pressure. Ambient pressure of 10^{-9} mm Hg.

3.15.3.2 Temperature. Ambient temperature of the mounting surface and inlet gas temperature will be +40 to $+140^{o}F$.

3.15.3.3 Radiation. Radiation exposure of 0.3 roentgens per hour for a three month period.

3.15.3.4 Life. This mission life is 3 months during which time the following shall be considered to apply.

3.15.3.4.1 The unit may be cycled 1000 times with flow being required through the subject unit for the majority of the time and the flow demand varying from 0 to 0.15 SCFM.

3.15.3.4.2 The flow time per actuation is from several seconds to one month and the total flow time will be that required to deplete a three cubic foot tank from 2500 psig to 100 psig at the average flow rate of 0.01 SCFM.

3.15.3.4.3 The time between actuation of the downstream solenoid valves will be from once per hour to once per month.

3.15.4 Operating Fluid. The operating fluid will be hydrogen or oxygen gas, dried to a dew point of -65°F, with an oil contamination less than 25 parts per million, with 98% of the particles having a diameter less than 5 microns and 100% having a diameter less than 12 microns.

3.15.5 System Definition. The unit must meet the requirements of this specification when used in a system consisting of the following: Tank, tubing of insignificant pressure drop, filter, subject unit, tubing having a volume of 0.25 in^3 and a negligible pressure drop, solenoid valve, volume of 1 to 400 in^3 and solenoid valve.

3.15.6 Regulating Flow Range. The flow range for which the specified outlet pressure must be maintained is 1 scc/min to 0.20 SCFM.

3.15.7 Operating Pressure will vary from 0 to 3000 psig to 0 psig. The rate of pressure change may be up to 3000 psi per second.

3.15.8 Proof Pressure. The function of the unit shall not be impaired by operation with a pressure of 3750 psig applied to the inlet port or by a pressure of 30 psig applied to the outlet port.

3.15.9 Burst Pressure. The unit shall be capable of withstanding a pressure of 6250 psig applied to the inlet port or a pressure of 50 psig applied to the outlet port without rupture of internal or external parts.

3.15.10 Sustained Pressure. The function of the unit shall not be impaired by having the unit supplied with proof pressure for three months at a vacuum level of 10^{-9} mm Hg Absolute with the unit locked-up.

3.15.11 Reliability. The unit shall be designed such that each unit delivered will have a reliability of 0.999 for meeting the requirements specified herein.

3.16 Performance Requirements. The requirements shall be met throughout the life of the unit.

3.16.1 Regulated Pressure. For a flow of .01 SCFM and an inlet pressure of 1250 psig, the outlet pressure shall be maintained within the limits of 15.0 $\pm$ 0.15 psig. An additional $\pm$ 0.50 psi is permissible if the additional inaccuracy is a similar and repeatable function of flow temperature, pressure or other specific input parameter for all units over the ranges specified herein.

3.16.2 Lockup Pressure. Slow lockup is defined as the outlet pressure obtained when slowly reducing flow from a regulating condition with a hand valve until a no-flow condition exists. Surge lockup is defined as the outlet pressure obtained when rapidly reducing flow as by a solenoid valve (10 millisecond poppet movement) from a regulating condition until a no-flow condition exists. After any flow up to 0.15 SCFM is slowly or suddenly interrupted with a volume between the unit and the solenoid valve as specified in paragraph 3.15.5 the outlet pressure shall not be more than 0.5 psi above the nominal regulated pressure. An additional $\pm$ 0.50 psi tolerance is permitted if the additional inaccuracy is a similar and repeatable function of flow, temperature, pressure or other specific input parameter for all units.

3.16.3 Leakage

3.16.3.1 External. The total external leakage shall not exceed 2 scc per hour at any pressures up to the proof pressures.

3.16.3.2 Internal. The total internal leakage, leakage through the outlet port, shall not exceed 2 scc per hour at lock-up conditions.

3.16.4 Relief Valve.

3.16.4.1 Reseat Pressure. After the relief valve has been caused to relieve, the relief valve shall be reseated, upon reducing the outlet pressure, to the extent of the total external leakage not exceed 3 scc per hour at 1.5 psi above the nominal regulated outlet pressure.

3.16.4.2 Cracking Pressure. Upon application of pressure to the outlet port the relief valve shall pass a flow of not less than 10 scc per minute at 2 psi above the nominal regulated outlet pressure.

3.16.4.3 Relieving Pressure. Upon increasing the outlet pressure to 5 psi above the nominal regulated outlet pressure, the relief valve flow shall not be less than 0.25 SCFM.

3.16.5 Transient Response. The outlet pressure shall be within the requirements of paragraph 3.16.1 within 0.20 seconds after the effect of a flow demand within the flow range specified herein is realized at the outlet port of the unit with a downstream volume of 1 in^3. During the 0.20 seconds the outlet pressure shall not exhibit peak deviations in excess of 1 psi nor shall the average pressure exceed 0.5 psi from the performance specified in paragraph 3.16.1. After the 0.20 seconds there shall be no periodic oscillation or wander.

4. QUALITY ASSURANCE PROVISIONS

4.1 Test Responsibility. The Vendor shall and the Purchaser will conduct tests on completed units to ascertain that the units meet the requirements of this specification.

4.1.1 Tests shall be conducted by the Vendor in accordance with any QAP (Quality Assurance Provision) or other test requirements that are referenced on the purchase order for the units.

4.1.2 Performance tests shall be conducted by the Vendor in accordance with paragraph 4.4.1. A data sheet shall be provided with each unit showing its performance.

4.1.3 The Vendor should conduct any additional tests that he deems necessary to ascertain that the unit will meet the requirements of this specification.

4.1.4 Additional testing will be conducted by the General Electric Company as specified in Section 4 of this specification. This testing may repeat any or all tests performed by the Vendor and may include tests in addition to those specifically called for in Section 4 to verify design requirements of the unit delineated in Section 3 of this specification.

4.2 Test Accuracy, Conditions, and Reports

4.2.1 Test Accuracy. All pressure, temperature, electrical, air flow, etc., measurements specified in this specification are true values. Assuming that it were possible to set, control, measure and read all test parameters to the exact true value, the exact characteristics and performance would be determined. Since this is not possible, however, it is required that the cumulative effect of all instrumentation and control inaccuracies plus possible setting and reading errors shall not result in a difference of more than plus or minus four percent between the true values and recorded values.

4.2.2 Test Conditions. The Vendor shall agree to the establishment of accepted test procedures and test conditions so that the development, qualification and production quality control shall be most efficiently accomplished. The establishment of test conditions shall be at the recommendation of the Vendor and the approval of the Purchaser. A 5 micron nominal, 12 micron absolute filter shall be used immediately upstream of the unit. All tests shall be conducted in chronological order as given herein. Nitrogen or helium gas shall be used unless otherwise specified. Helium shall be used for the Functional Leakage Tests; the leakage limits given herein shall apply when using helium.

4.2.3 Test Conditions. Unless otherwise specified, Functional Tests shall be conducted under the following conditions:

(a) Temperature, $25^{\circ}C \pm 10^{\circ}C$.

(b) Relative Humidity, 90% or less.

(c) Barometric Pressure, 28 to 32 inches of mercury.

4.2.4 Chamber Volume. The units being tested plus associated test equipment shall not exceed 50% of the internal volume of the test chamber.

4.2.5 Temperature Definition. For temperature tests at pressures greater than 10^{-1} mm Hg, the temperature referred to is ambient air temperature. In these tests the heat sources shall be such that radiant heat is not directed on the unit. For temperature tests under vacuum, pressure less than 10^{-4} mm Hg, temperatures are the mounting surface temperature.

4.2.6 Temperature Tests. During performance testing under temperature environmental conditions the entire system, including a gas supply reservoir, shall be placed in the temperature chamber and the gas temperature is to be within $\pm 3^{\circ}F$ of the environmental temperature. Expansion and escape of entrapped gas within the test hardware is not to be misconstrued as leakage. Any escapement shall cease after temperature stabilization.

4.2.7 Rejection and Retest. When a unit fails to meet the specification, acceptance of any additional units shall be withheld until the extent and cause of failure has been determined. After required corrections or changes have been made, all necessary tests shall be performed again. Acceptance of additional units will be resumed when three additional units have successfully passed the tests which resulted in initial failure. A failure report shall be prepared on each failure.

4.3 Classification of Tests. The unit shall be submitted to the following classes of tests.

4.3.1 Functional Tests. Tests conducted to determine that each unit operates satisfactorily within the performance specified in this specification at sea level static conditions. These tests are defined in paragraph 4.4.1 and are to be conducted on units in accordance with the following:

4.3 1.1 After final assembly of each unit and prior to shipment to the Purchaser, or after any repair or modification of a unit. If the performance at conditions other than the Test Conditions stated in paragraph 4.2.3 differs notably from that at the conditions per paragraph 4.2.3, the acceptable performance applicable at these conditions shall be restricted so as to assure that the performance of the unit will be satisfactory at all other conditions required by this specification.

4.3.1.2 During Acceptance and QualificationTesting as specified in paragraphs 4.4.2 and 4.4.3.

4.3.2 Quality Assurance Tests. Tests conducted at the discretion of the Purchaser at simulated flight environments to determine that the integrity of units is continually such as to be suitable for flight. These tests are defined in paragraph 4.4.2 and will be

conducted by the Purchaser. Failure of the unit to successfully complete these tests will be cause for rejection per paragraph 4.2.7.

4.3.3 Qualification Tests. Tests conducted at simulated flight environments to acquire assurance that the unit is capable of performing satisfactorily and reliably for the duration of the intended service life as defined herein. These tests are defined in paragraph 4.4.3. At its option, the Purchaser may select units built to production drawings to be subjected to the Qualification Tests specified herein and performed either by the Purchaser or by the Vendor on a supplementary order to establish conformance with this specification. If units are shipped to the Purchaser prior to successful completion of these tests, the Vendor will be financially responsible for modifying the units shipped with such changes as may be required to acquire successful completion of these tests. Throughout these tests the performance of the unit shall be within the performance specified in this specification. If and as failures occur on the initial qualification attempt, the unit shall be repaired and the test continued on this unit until the unit has completed all tests. The failures shall be analyzed and improvements incorporated into the unit to be used for the second qualification attempt. Failure of the unit to successfully complete these tests will be cause for rejection per paragraph 4.2.7.

4.4 Test Methods. The reference port shall be open to ambient pressure for all testing.

4.4.1 Functional Tests.

4.4.1.1 Physical Examination. Each unit shall be examined to determine conformance with this specification, with the applicable General Electric Drawing and with regard to material, workmanship, construction and marking.

4.4.1.2 Proof Pressure. With the outlet port capped apply the proof pressure to the inlet port. Note any gas leakage or high pressure effects for one minute.

4.4.1.5 Static Leakage

4.4.1.5.1 External. With the outlet capped and the unit energized apply the proof pressure to the inlet port and measure external leakage, and read the outlet pressure. Repeat for a pressure of 200 psig. From an external supply increase the outlet pressure to 17.0 psig long enough to establish that the relief valve is passing flow. Reduce the outlet pressure to 16.5 psig and read the leakage.

4.4.1.5.2 Internal. With the outlet shut off apply the proof pressure to the inlet port. Establish a flow of at least 0.01 SCFM through the unit by partially opening the downstream valve for approximately one minute. Shut off the downstream valve slowly. Read the outlet pressure. Maintain these conditions for two hours. Read the pressure after each hour. Reduce the inlet pressure to 200 psig. Establish a flow of at least 0.01 SCFM through the unit by partially opening the downstream valve for approximately one minute. Shut off the downstream valve slowly. Read the outlet pressure. Maintain these conditions for two hours. Read the pressures after each hour. This test shall be performed with a known small volume on the outlet for the purpose of calculating leakage.

4.4.1.3 Regulated and Lockup Pressure. With the outlet shut off so there is no flow demand on the unit apply an inlet pressure of 3000 psig and read the outlet pressure for flows of 0, .01, .04, .08, .15, .10, .05, .01 and 0 SCFM. Repeat for an inlet pressure of 200 psig.

4.4.1.4 Relief Valve Crack and Flow. With the inlet shut off apply an outlet pressure of 17.0 psig and measure flow from the relief valve. Increase the outlet pressure to 20 psig and measure flow from the relief valve.

4.4.2 Quality Assurance Tests. The Functional Tests of paragraph 4.4.1 shall precede and follow this series of tests. No deterioration in performance is permissible during these tests. Performance at all conditions must be within design limits as specified herein.

4.4.2.1 Vibration Test.

4.4.2.1.1 Shaker-Fixture Unit Resonance Test. Prior to performing the vibration test, if an identical unit and an identical fixture have not been previously vibrated in the machine to be employed for the vibration test, one unit shall be subjected to vibration in each of its three mutually perpendicular axes through the frequency range of from 10 to 3000 cps. If any alterations are made in the machine, fixture or unit, or if a different machine or fixture is employed, this test shall be repeated. The unit shall be attached to the test fixture through the attachment points in such a manner as to provide no additional stiffness or restraint other than at the attachment points. The vibration response shall be monitored through the entire frequency range in three mutually perpendicular directions at each attachment point of the unit to the fixture. The amplitude readings normal to the direction of excitation shall be no greater than 50% of the maximum level in the direction of excitation. The maximum and minimum amplitude readings taken in the direction of shake at the attachment points shall not differ from each other by more than 50%.

The unit-fixture-table combination shall be altered until these conditions are satisfied. The frequency sweep shall be manually controlled to insure that all resonances observed at the attachment points are fully excited. Resonant frequencies, bandwidth, and amplification of all resonances shall be noted and recorded. The vibration amplitude shall be varied with frequency such that the amplitude at the attachment points is as follows:

Frequency	Amplitude
5 to 20 cps	0.2 inches peak to peak
20 to 3000 cps	2 g's

4.4.2.1.2 Sinusoidal Vibration. The unit shall be subjected to sinusoidal vibration along each of its three mutually perpendicular axes with the amplitudes as specified in paragraph 3.15.2.3.2. The sinusoidal vibration shall be swept once at approximately two octaves per minute. During this test, the unit shall be pressurized to 3000 psig and the leakage shall be monitored.

4.4.2.1.3 Random Vibration. Random Gaussian vibration shall be applied to the unit for a period of 10 minutes over a frequency range of 20 to 2000 cps at 15 g's rms along each of its three mutually perpendicular axes. During this test the unit shall be pressurized to 3000 psig and the leakage shall be monitored.

4.4.2.2 High Temperature Test. The unit shall be placed in a test chamber and 3000 psig applied to the inlet port with an orifice on the downstream to permit a flow of 0.10 $\pm$ 0.01 SCFM. The ambient pressure shall be reduced to less than 0.25 psia. The temperature of the unit and the gas shall be raised to 140^{o}F while maintaining the 3000 psig inlet pressure. The volume of the supply tank shall be 14 $\pm$ 3 in.^{3}. The unit shall then be cycled 60 times at the rate of 1 cycle per minute having flow for approximately 50 seconds each cycle. The conditions shall be maintained for 5 hours while monitoring the outlet pressures and leakage. Establish an inlet pressure of 1500 psig and continue the test for another hour. Perform the test of 4.4.1.3.

4.4.2.3 Low Temperature Test. This test shall be performed as in paragraph 4.4.2.2 except using a temperature of 40^{o}F.

4.4.3 Qualification Tests.

4.4.3.1 Function and Environment Qualification. The following tests shall be performed on a single unit. The unit shall have passed the Quality Assurance Tests prior to being subjected to this test and shall pass the Quality Assurance Tests (except for vibration which shall not be done) upon completion of these tests. Prior to and after the tests of each sub-paragraph of this paragraph, i.e., 4.4.3.1.1, 4.4.3.1.2, etc., the unit shall be subjected to and pass the Functional Test of paragraph 4.4.1, except the test of 4.4.1.2, shall be performed on the last Functional Test only. Performance must be within design limits as established herein throughout all tests. No adjustment or disassembly whatsoever is permissible except for the teardown inspection after the test.

4.4.3.1.1 Transportation and Storage Tests.

4.4.3.1.1.1 While non-pressurized and with shipping plugs loosely installed in the ports, the unit shall be subjected to an ambient temperature of -35^{o}F and shortly thereafter to an ambient pressure of 87.5 mm Hg. Abs. These conditions shall be maintained for eight hours at

which time the pressure shall be returned to atmospheric and subsequently the temperature shall be returned to room temperature. The rate of pressure change shall not exceed 200 mm Hg. per minute.

4.4.3.1.1.2 While non-pressurized the unit shall be subjected to an ambient temperature of $+160^{\circ}F$ with a relative humidity of less than 5% for eight hours at which time atmospheric conditions shall be restored.

4.4.3.1.1.3 While non-pressurized and with shipping plugs loosely installed in the ports, the unit shall be subjected to a temperature of $120^{\circ}F$ and a relative humidity of at least 95% for a period of 24 hours. Distilled or demineralized water having a ph value of between 6.5 and 7.5 at $25^{\circ}C$ ($77^{\circ}F$) shall be used to obtain the desired humidity. The velocity of the air within the chamber shall not exceed 150 ft/min.

4.4.3.1.2.1 System Charging Test. With the outlet port capped increase the inlet pressure from 0 to 100 psig slowly reading outlet pressure as a function of inlet pressure. Continue for inlet pressures to 3000 psig and back to 0 psig.

4.4.3.1.2.2 Response Test. With a system as defined in paragraph 3.15.5 make transient recordings of the response of the unit to actuation of the two downstream solenoid valves in the opening and closing directions for inlet pressures of 3000, 2500, and 200 psig inlet pressure for a flow of .02 $\pm$ 0.002 SCFM and 0.15 $\pm$ 0.01 SCFM for a volume of 25 in^3. Ambient pressure shall be reduced to less than 0.25 psia just prior to the actuation at 3000 psig and shall be maintained below this pressure for the remaining actuations. The actuation at 3000 psig shall show the response subsequent to the ambient pressure change as during the first actuation after launch. The recording shall show performance for at least 0.5 seconds. Sufficient time shall be provided between each solenoid valve actuation to acquire steady state conditions. The response of the transient recording equipment shall be such as to have an attenuation of no more than 3 db at 600 cps.

4.4.3.1.2.3 Vibration Test. This will have been accomplished in the Quality Assurance Test.

4.4.3.1.2.4 Acceleration Test. The unit shall be exposed to a steady state acceleration of 18.5 g's for a period of not less than 4.5 minutes in both directions along the three mutually perpendicular axes. During this test, the unit shall be pressurized to 3000 psig and the leakage monitored.

4.4.3.1.2.5 Shock Test. The unit shall be subjected to three 30 g shocks in each direction along the three mutually perpendicular axes for a total of 18 shocks. Time to peak of each shock shall be 6 ms. Duration of each shock shall be 12 ms. The shock intensity shall be within 10% of 30 g when measured with a filter having a bandwidth of 0 to 800 cps. The unit shall not be pressurized during this test. Duration of the pulse shall be that interval of time beginning when the amplitude first has a value which is 10% of the peak g and extending to the instant when the amplitude is again 10% of the peak value. Insofar as is possible the fixture to support the unit shall be free of resonance in the frequency range of 0 to 1000 cps.

4.4.3.1.6 Orbit Tests.

4.4.3.1.6.1 Thermal/Vacuum Test. The unit shall be placed in a test chamber and 3000 psig applied to the inlet port. A minimum distance of three inches between components and the chamber wall and between the test component and other components shall be maintained. The ambient pressure shall be reduced to 1×10^{-6} mm Hg. The inlet gas supply shall be from a 2 ft.^{3} container. Flow shall be 0 to 0.15 SCFM during flow conditions. Monitor external leakage and outlet pressure throughout the test. While at this ambient pressure the following thermal/vacuum test schedule shall be followed:

(a) With an inlet pressure of 3000 psig allow a continuous flow for 24 hours at room temperature at 0.01 SCFM.

(b) With the 3000 psig cycle the flow rate between values within the range of 0.01 to 0.15 SCFM 288 times at the rate of 12 cycles per hour with flow on for 4.5 minutes per cycle. Inlet pressure shall be 3000 psig at the start of the test and shall not be recharged until the inlet pressure drops below 150 psig. Six hours after the start of cycling and for 12 hours thereafter, the flow during the "flow-on" time shall be 0.01 ± 0.05 SCFM. During the last eight hours increase the temperature to +150°F.

(c) Repeat "a" at the 150°F temperature.

(d) Repeat "b" reducing the temperature to +30°F during the last eight hours.

(e) Repeat "a" at the 30°F temperature.

(f) Repeat "b" increasing the temperature to room temperature during the last eight hours.

(g) Repeat "a" at room temperature.

5. PREPARATION AND DELIVERY

5.1 Preservation. All ports shall be suitably protected to exclude foreign matter in such a way that the unit can not be assembled into a system without removal of the protective cover. Threaded parts shall be protected with a threaded-type cap or plug. Covers used to protect flange-type pads shall cover the entire pad surface including all threaded holes and other openings not used to retain the cover.

5.2 Interior Packages

5.2.1 Packaging. The component shall be sealed in the polyethylene or nylon bag of a thickness of at least 5 mills. The component and bag shall be enclosed in a container which provides protection of the component during shipment and handling. The ports of the component shall be closed with one of the following:

1. GEON 121 Polyvinyl chloride caps or similar plastic as specifically approved by GE/MSD. Polyethylene caps are specifically prohibited.

2. Nylon tape or 5 mill minimum polyethylene film over the ports, provided the tape is not applied to the thread.

All packaging material in contact with the component shall be cleaned to the same level as specified in paragraph 3.9 herein.

5.2.2 Each interior package shall be durably and legibly marked with the following information where applicable in such a manner that

the markings will not become damaged when the packages are opened:

(a) Name of the unit,

(b) Purchaser's order number,

(c) Vendor's name,

(d) Serial Number,

(e) General Electric part number, and

(f) Cleaning information per 118A1630.

5.3 Exterior Packages.

5.3.1 Packaging and Packing. Unless otherwise specified, the interior packages shall be packed in a substantial commercial exterior shipping container constructed to insure acceptance by common or other carrier for safe transportation at the lowest rate to the point of delivery.

5.3.2 Marking. The exterior shipping container shall be marked in accordance with MIL-STD-129.

5.4 Transportation. The unit shall be packaged for shipment in such a manner as to withstand, without physical or functional damage, conditions as encountered in domestic shipment in accordance with commercial procedures. To avoid temperature below -35°F during air travel, the shipment shall be marked "Restricted Air Transportation."

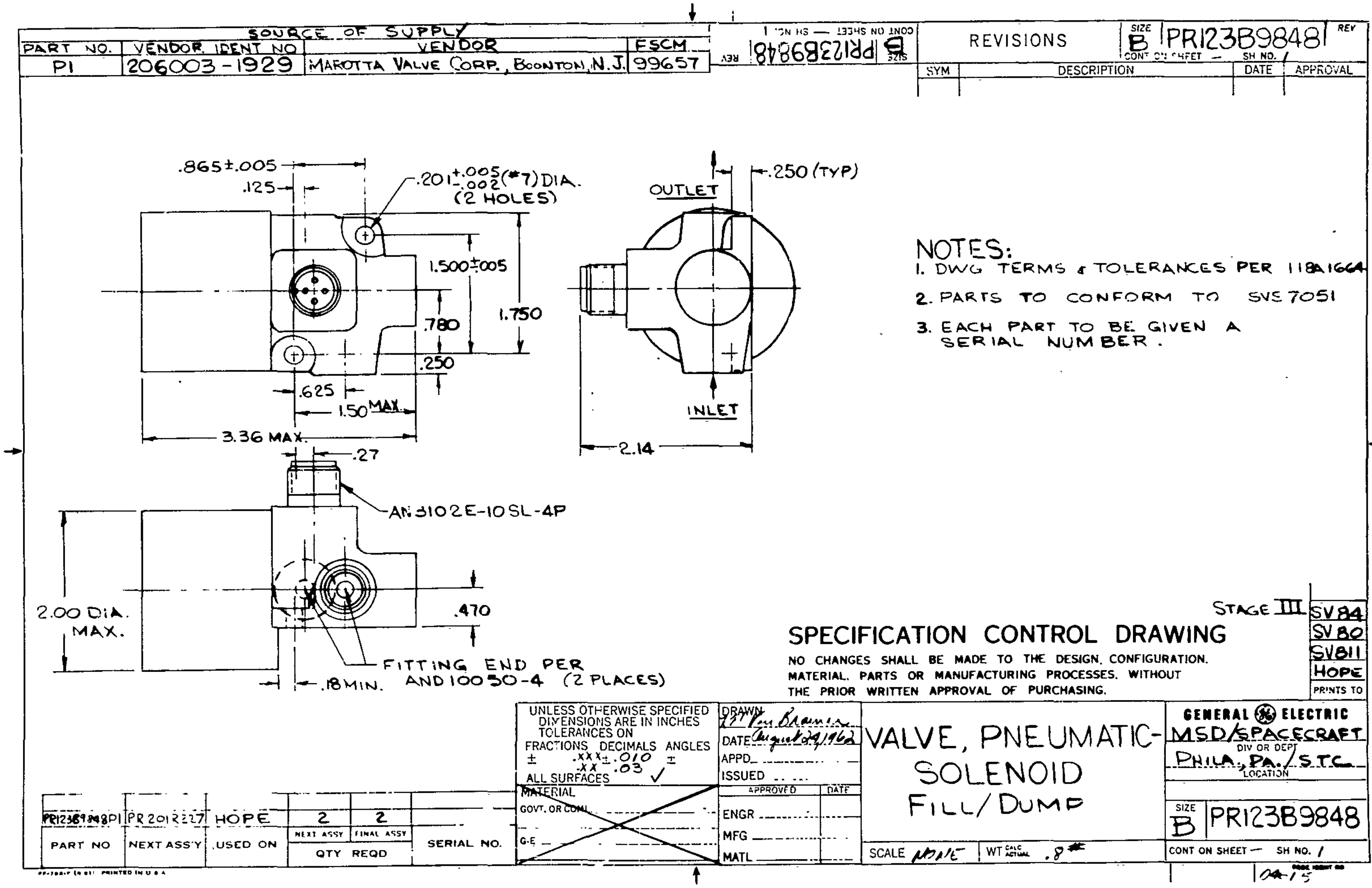


Figure 3A1. Valve, Pneumatic Solenoid Fill/Dump

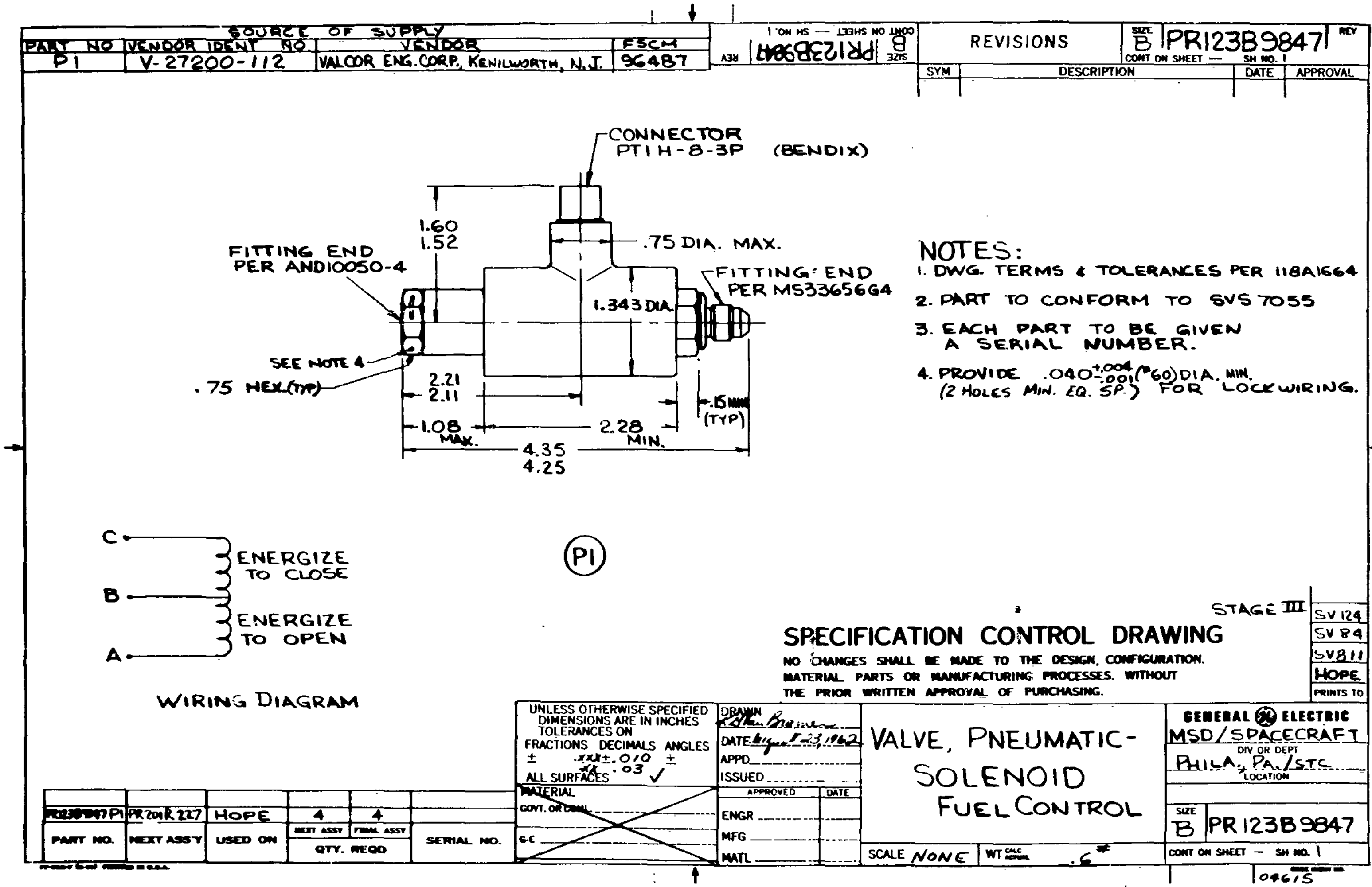


Figure 3A2. Valve, Pneumatic Solenoid Fuel Control

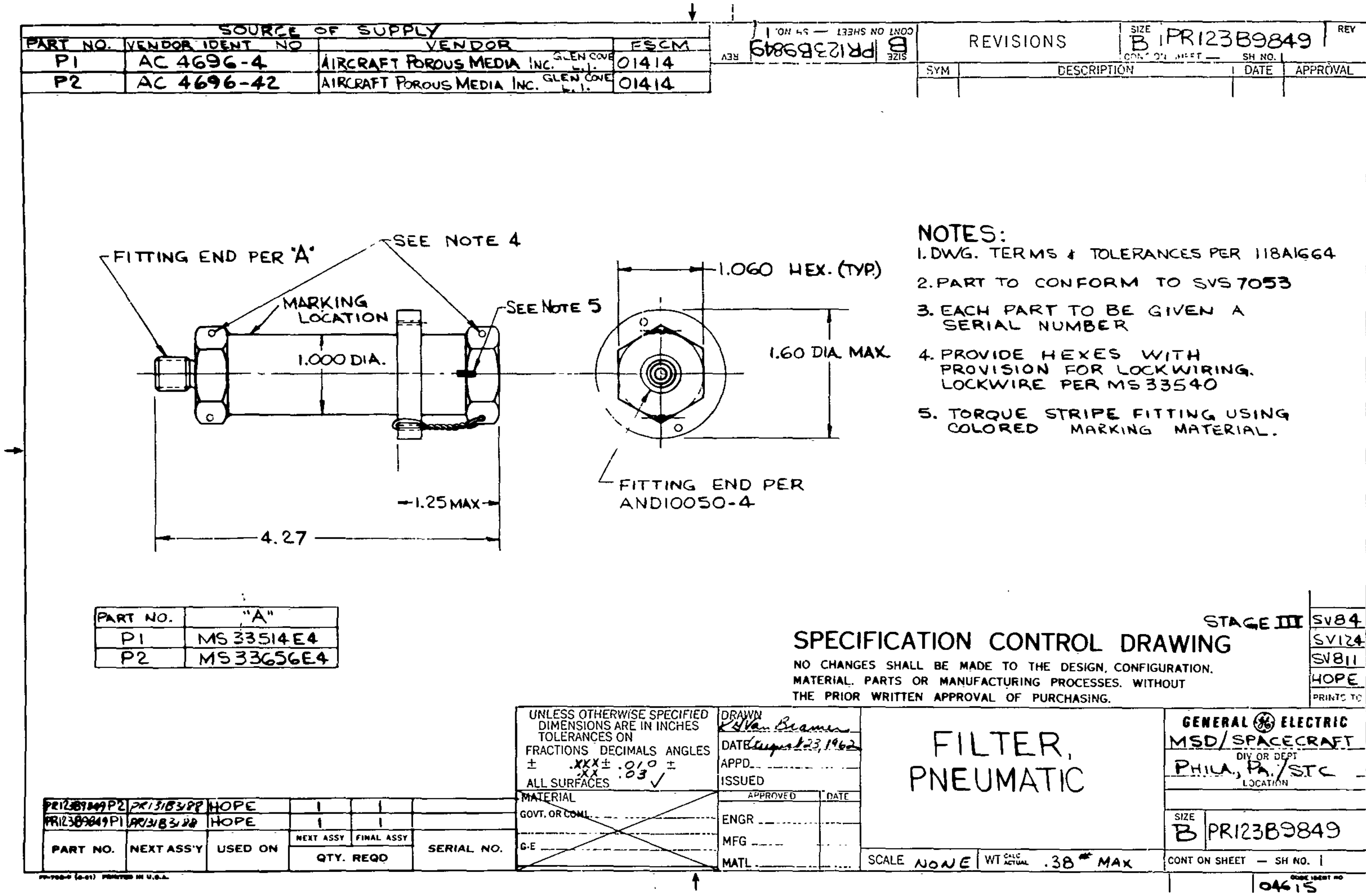


Figure 3A3. Filter, Pneumatic

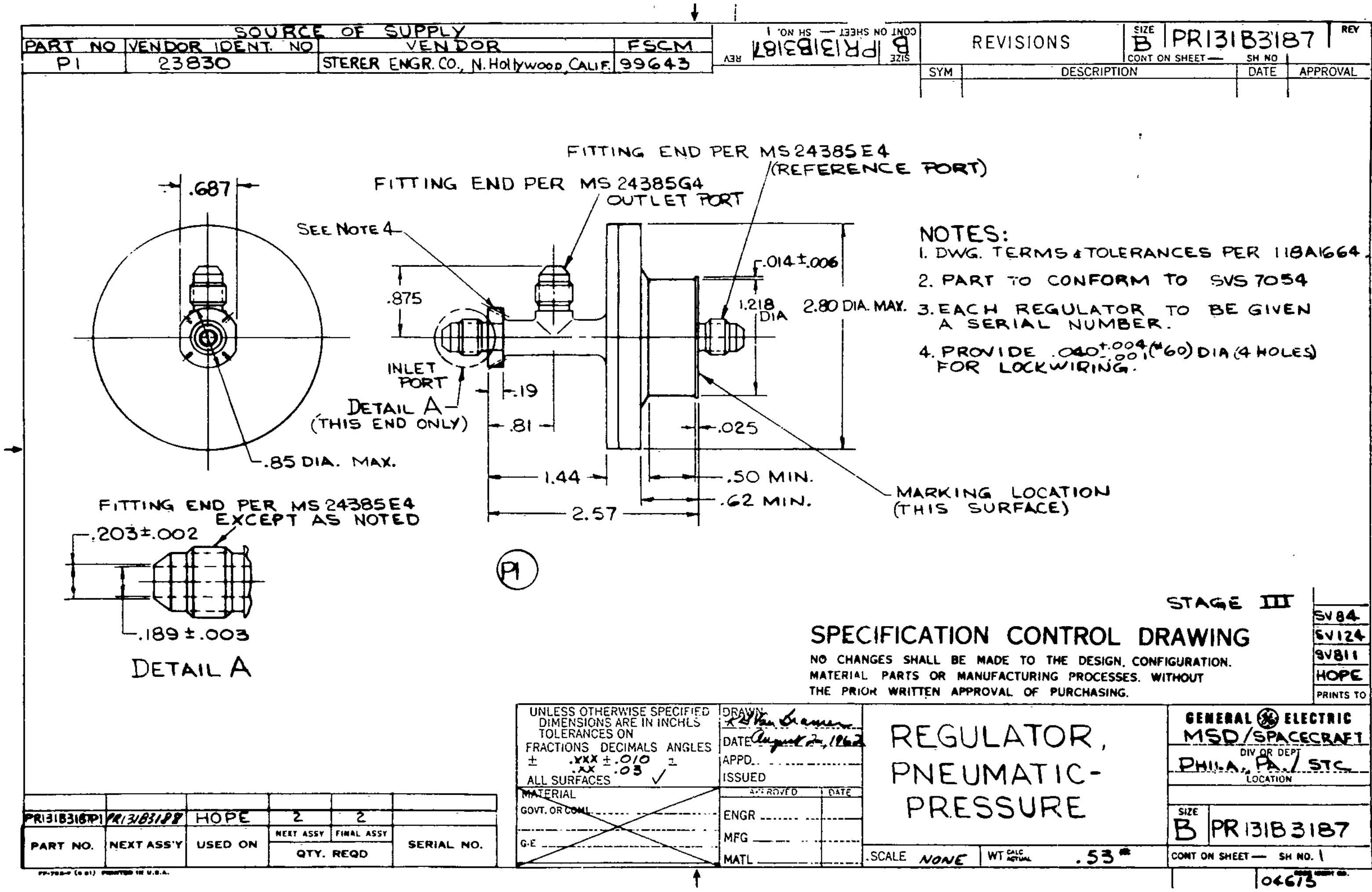


Figure 3A4. Regulator, Pneumatic Pressure

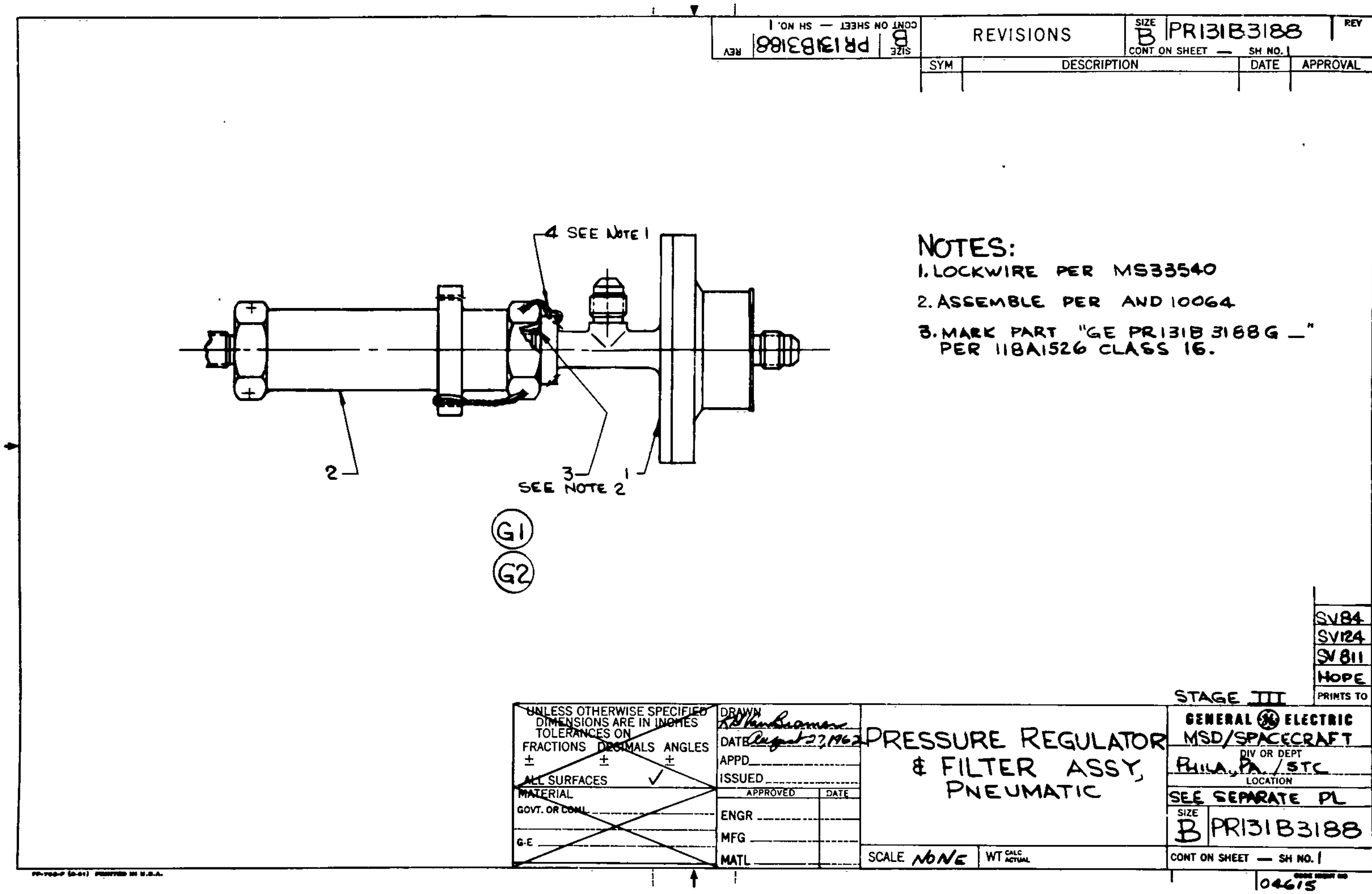


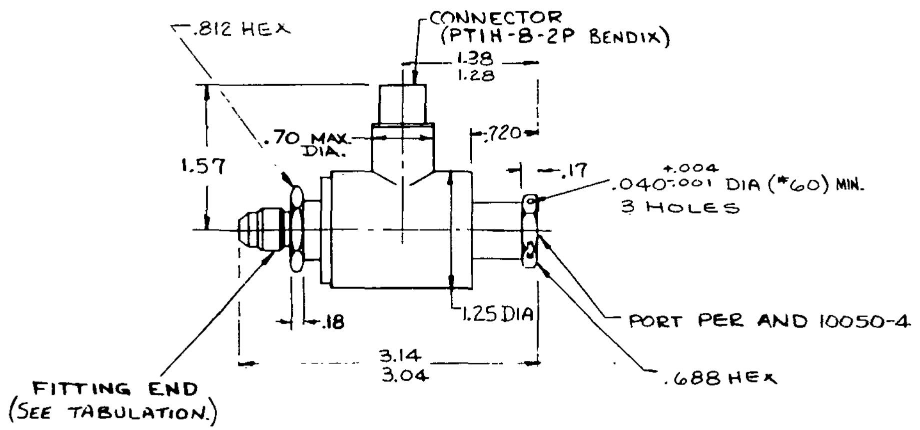
Figure 3A5. Pressure Regulator and Filter Assembly, Pneumatic

SOURCE OF SUPPLY			
PART NO.	VENDOR IDENT NO	VENDOR	FSCM
P1	V-27200-111	VALCOR ENG. CORP, KENILWORTH, N.J.	96487
P2	V-27200-115	VALCOR ENG.CORP., KENILWORTH, N.J.	96487

CONT ON SHEET — SH NO. 1 SIZE B PR123B9846 REV

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL

SIZE B PR123B9846 CONT ON SHEET — SH NO. 1 REV



NOTES:
1. DWG TERMS & TOLERANCES PER 118A1664
2. DETAIL & PERFORMANCE REQUIREMENTS PER SVS (SEE TABULATION).
3. EACH VALVE TO BE GIVEN A SERIAL NUMBER

PART NO	FITTING END	SVS
P1	MS 33656 E4	7056 A
P2	MS 33656 E4	7056 B
P3	MS 33657 E4	7056 B

STAGE III

SPECIFICATION CONTROL DRAWING

NO CHANGES SHALL BE MADE TO THE DESIGN, CONFIGURATION, MATERIAL, PARTS OR MANUFACTURING PROCESSES, WITHOUT THE PRIOR WRITTEN APPROVAL OF PURCHASING.

SV84
SV80
SV811
HOPE
PRINTS TO

PART NO.	NEXT ASS'Y	USED ON	QTY. REQD NEXT ASSY	QTY. REQD FINAL ASSY	SERIAL NO.
PR123B9846P2	PR201R227	HOPE	2	2	
PR123B9846P1	PR138 3490	HOPE	4	4	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS ± DECIMALS .xxx ± .010 .xx ± .03 ANGLES ±
ALL SURFACES √
MATERIAL
GOVT. OR COML
G-E

DRAWN Arthur Bremer
DATE August 24, 1962
APPD
ISSUED
APPROVED DATE
ENGR
MFG
MATL

VALVE, PNEUMATIC-
SOLENOID
PURGE CONTROL

SCALE NONE WT .4# MAX

GENERAL ELECTRIC
MSD/SPACECRAFT
DIV OR DEPT
PHILA., PA./STC
LOCATION

SIZE B PR123B9846
CONT ON SHEET — SH NO. 1
04615

Figure 3A6. Valve, Pneumatic Solenoid Purge Control

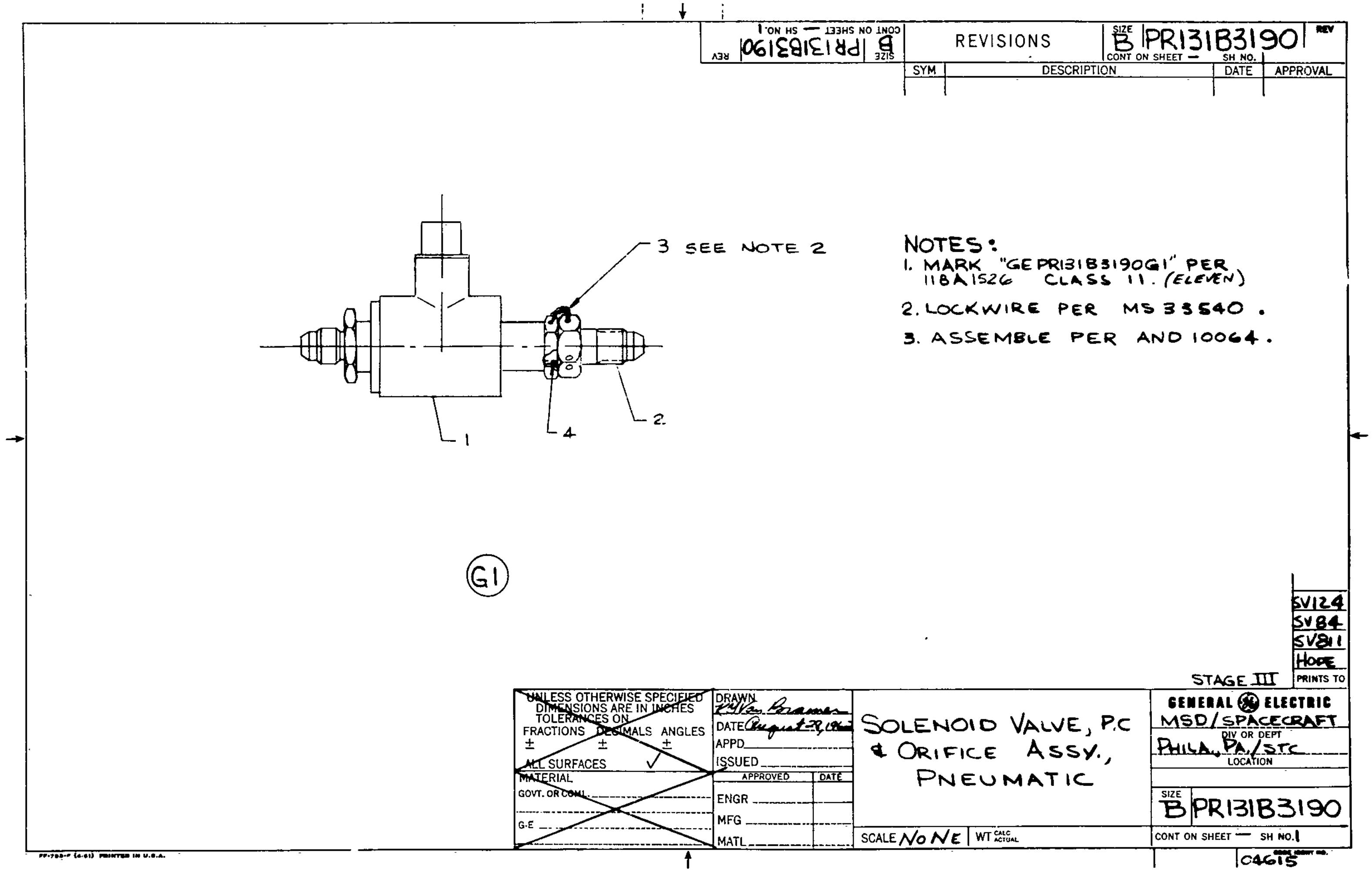


Figure 3A7. Solenoid Valve, P.C. and Orifice Assembly, Pneumatic

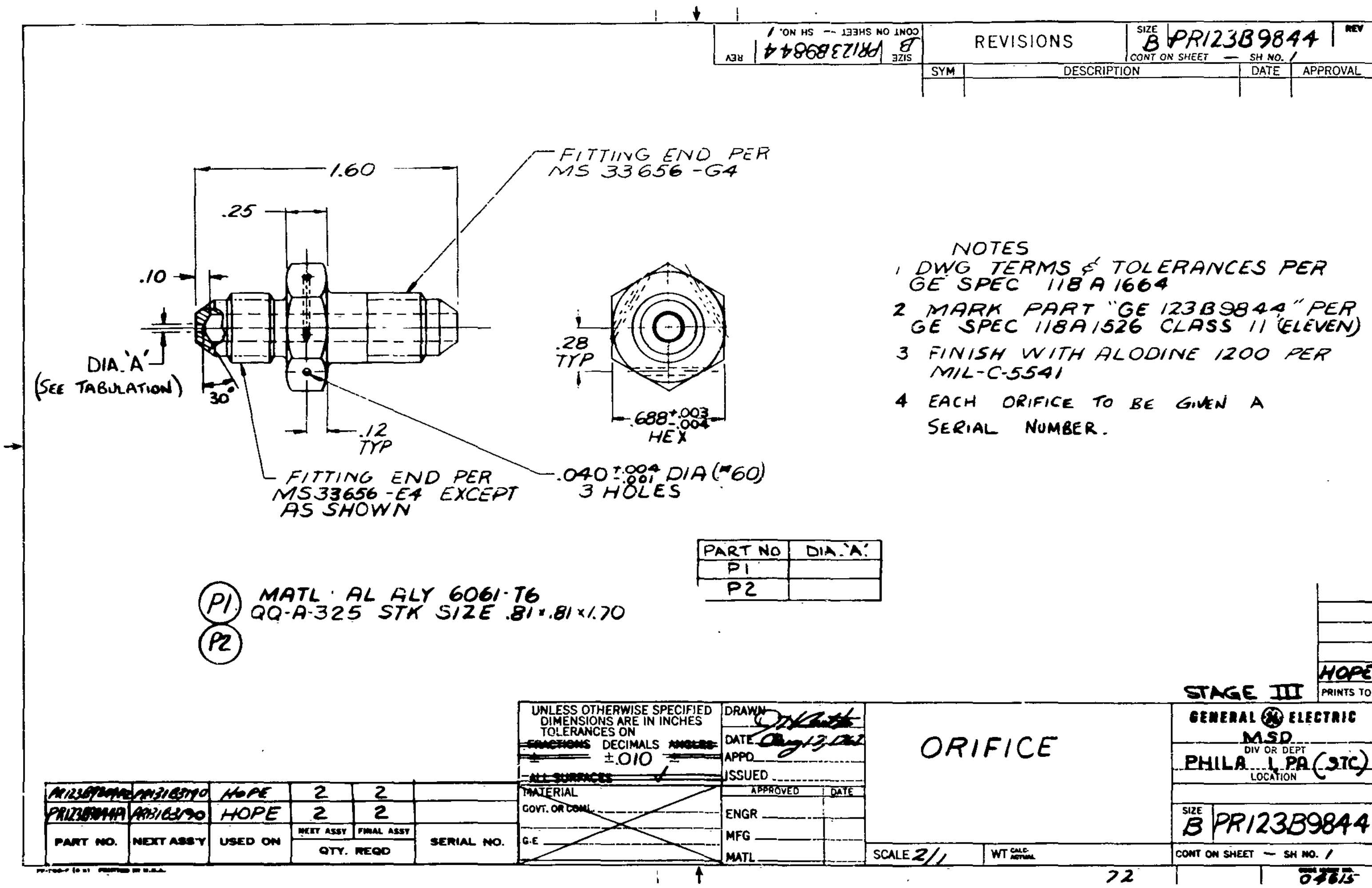


Figure 3A8. Orifice

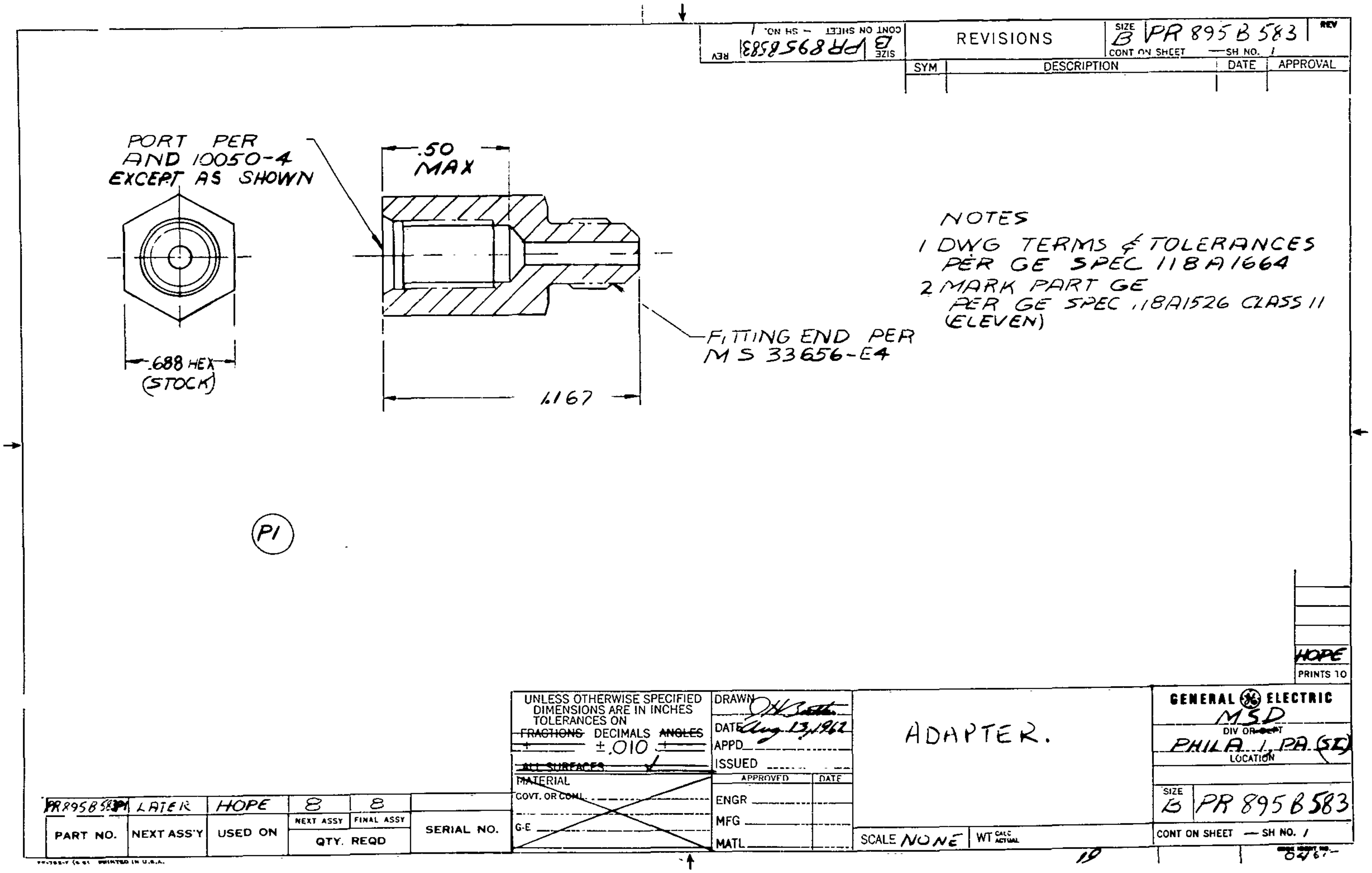
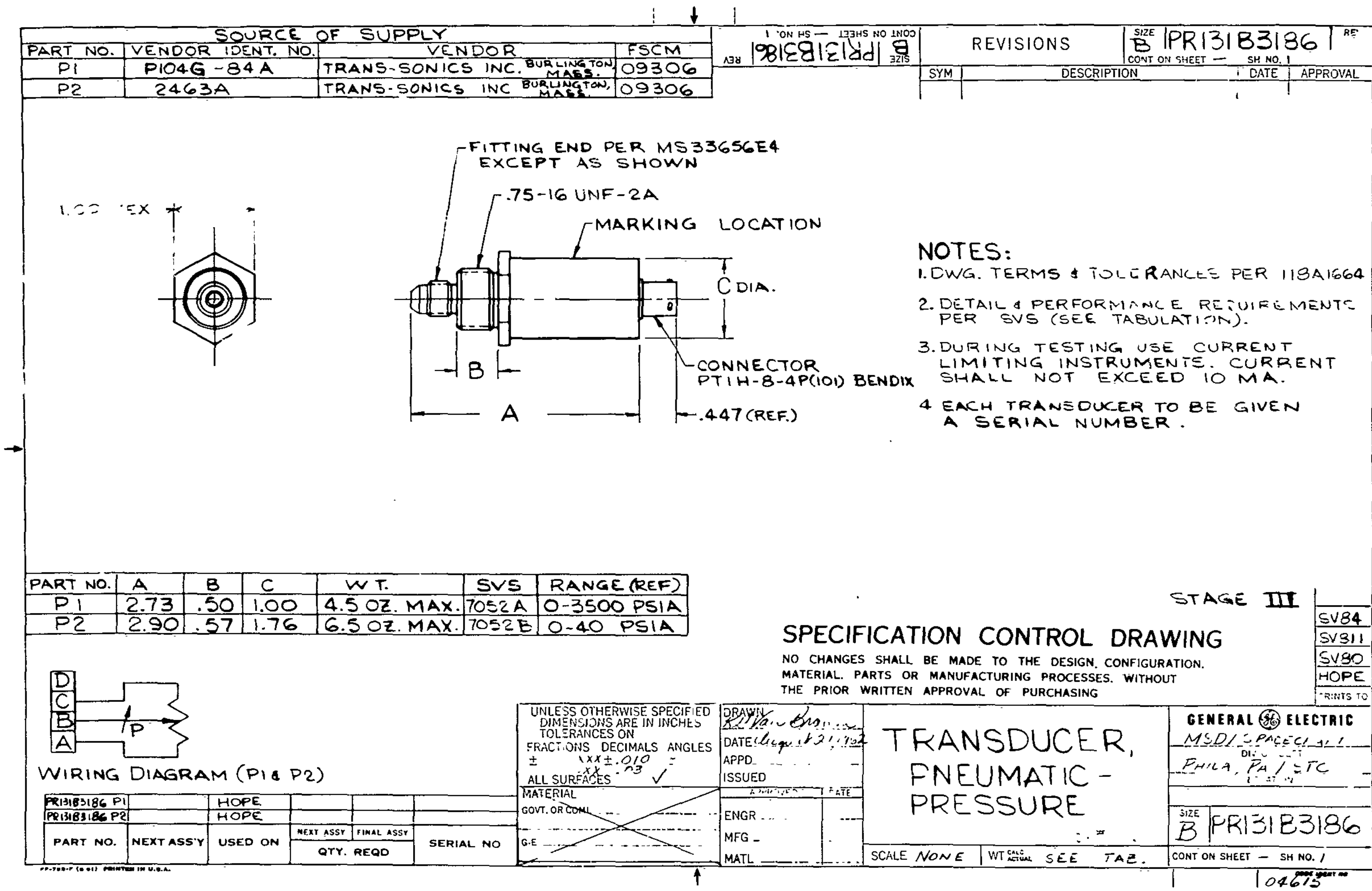


Figure 3A9. Adapter



SOURCE OF SUPPLY			
PART NO.	VENDOR IDENT. NO.	VENDOR	FSCM
P1	P104G-84A	TRANS-SONICS INC. BURLINGTON, MASS.	09306
P2	2463A	TRANS-SONICS INC BURLINGTON, MASS.	09306

PART NO.	A	B	C	WT.	SVS	RANGE (REF)
P1	2.73	.50	1.00	4.5 OZ. MAX.	7052A	0-3500 PSIA
P2	2.90	.57	1.76	6.5 OZ. MAX.	7052B	0-40 PSIA

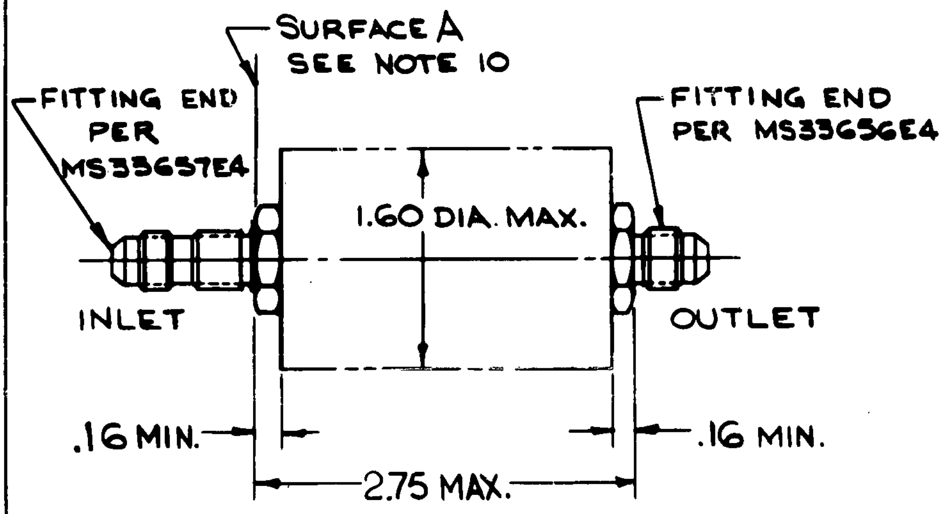
Figure 3A10. Transducer, Pneumatic-Pressure

GENERAL ELECTRIC

PR308A758
CONT ON SHEET 2 SH NO. 1

REV NO.	TITLE
PR308A758 CONT ON SHEET 2 SH NO. 1	QUICK DISCONNECT, PNEUMATIC FIRST MADE FOR

REVISIONS



P1

P2

P3

P4

PRINTS TO

MADE BY	APPROVALS	DIV OR DEPT	
[signature] August 29 1962 ISSUED		MSD PHILA., PA/STC LOCATION	PR308A758 CONT ON SHEET 2 SH NO. 1

PF-803 WP (4-62) REV.
PRINTED IN U.S.A.

CODE IDENT. NO.
04615

GENERAL ELECTRIC

PR308A758

CONT ON SHEET — SH NO. 2

REV NO.

PR308A258

CONT ON SHEET — SH NO. 2

TITLE

QUICK DISCONNECT, PNEUMATIC

FIRST MADE FOR

REVISIONS

1. The unit shall be suitable for hydrogen and oxygen service.

2. The external ambient pressure will be sea level static pressure except after satellite launch with the unit disconnected, the MS33657E4 end will be exposed to vacuums to 10^{-9} mm Hg. Abs (The unit is not required to function after launch.)

3. With the unit disconnected the MS33656E4 end shall seal the gas from escaping at pressures from 0 to 3000 psig applied to the outlet port with leakage less than 5 SCC/Hr. of helium and it shall prevent ambient air from entering the line with an internal line pressure down to 0.01 psia such that the leakage using helium will not exceed 5 SCC/Hr.

4. With the unit disconnected the MS33657E4 end shall be open to ambient pressure and shall pass a flow of at least 20 SCFM of nitrogen with a pressure of 100 psig applied to the inlet port.

5. With the two ends properly mated the external leakage shall not exceed 5 SCC/Hr. of helium out of the unit with pressures from 0 to 3000 psig and leakage into the unit of 5 SCC/Hr. with internal pressures down to 0.01 psia.

6. With the two ends properly mated the unit shall pass a flow in either direction of at least 20 SCFM of nitrogen when a pressure differential of 300 psi is maintained across the unit at pressures from 300 to 3000 psig.

7. The unit shall not be damaged by pressures up to the proof pressure of 3750 psig.

8. The unit shall show no signs of rupture up to the burst pressure of 6250 psig.

9. The above measurements shall be met for at least 500 matings and disconnections of the connector.

10. With the unit disconnected the length of the unit from Surface A to the internal end of the fitting shall not exceed 1.15 inches.

11. The weight shall be kept to a minimum.

12. The units shall be sealed in a plastic bag and tagged "Certified Clean for Oxygen Service".

13. The MS33656E4 end of any connectors P1, P2, P3, or P4 shall not mate with the MS33657E4 end of any of the other connectors.

PRINTS TO

MADE K. W. Van Kanner August 23, 1962

ISSUED

APPROVALS

MSD DIV OR DEPT

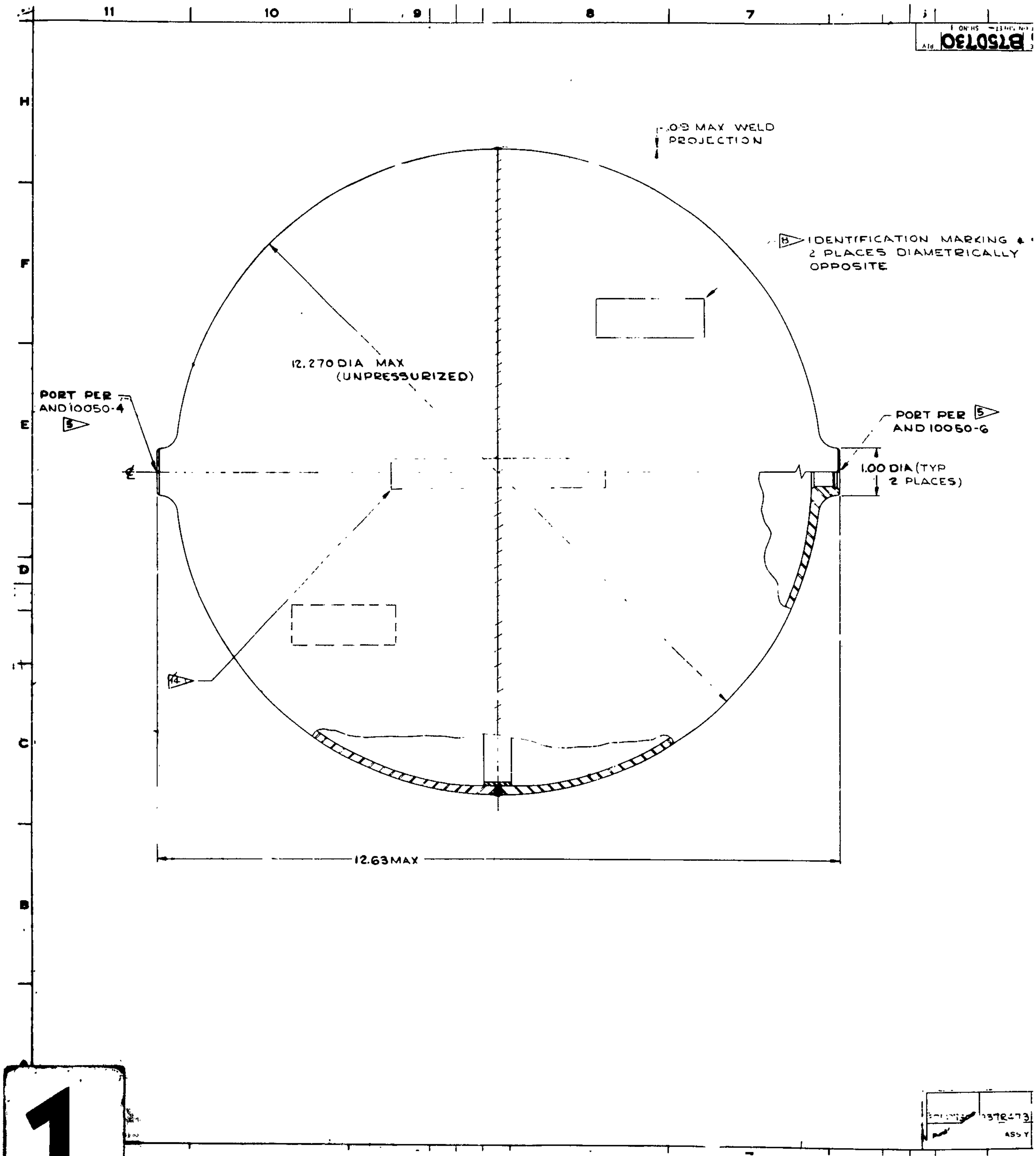
PHILA, PA/STC LOCATION

PR308A758

CONT ON SHEET — SH NO. 2

CODE IDENT. NO. 04615

PF-603 WP (4-68) REV.
PRINTED IN U.S.A.



.03 MAX WELD PROJECTION
IDENTIFICATION MARKING & 2 PLACES DIAMETRICALLY OPPOSITE
12.270 DIA MAX (UNPRESSURIZED)
PORT PER AND 10050-4
PORT PER AND 10050-6
1.00 DIA (TYP 2 PLACES)
12.63 MAX
ASSY

1

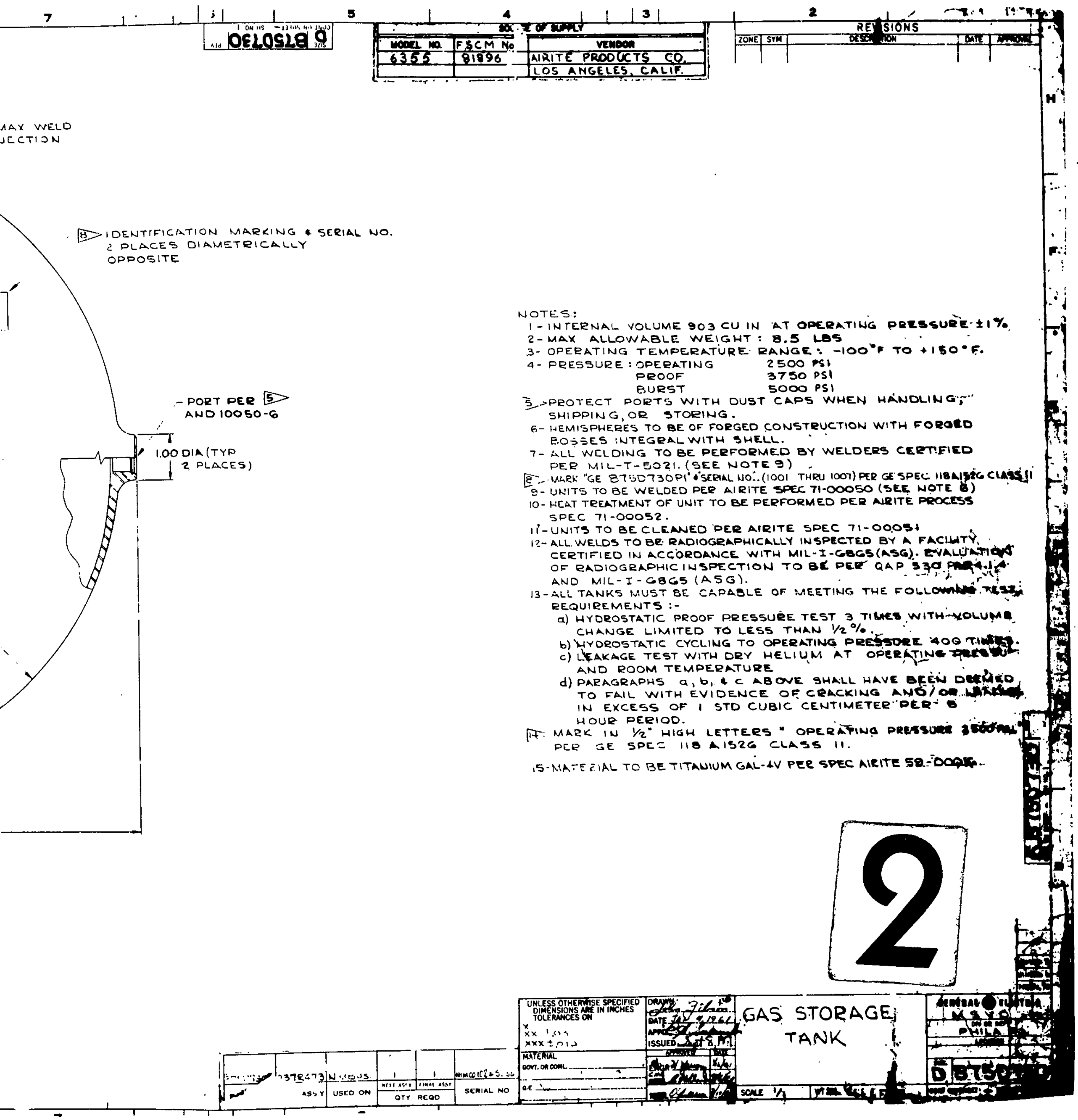
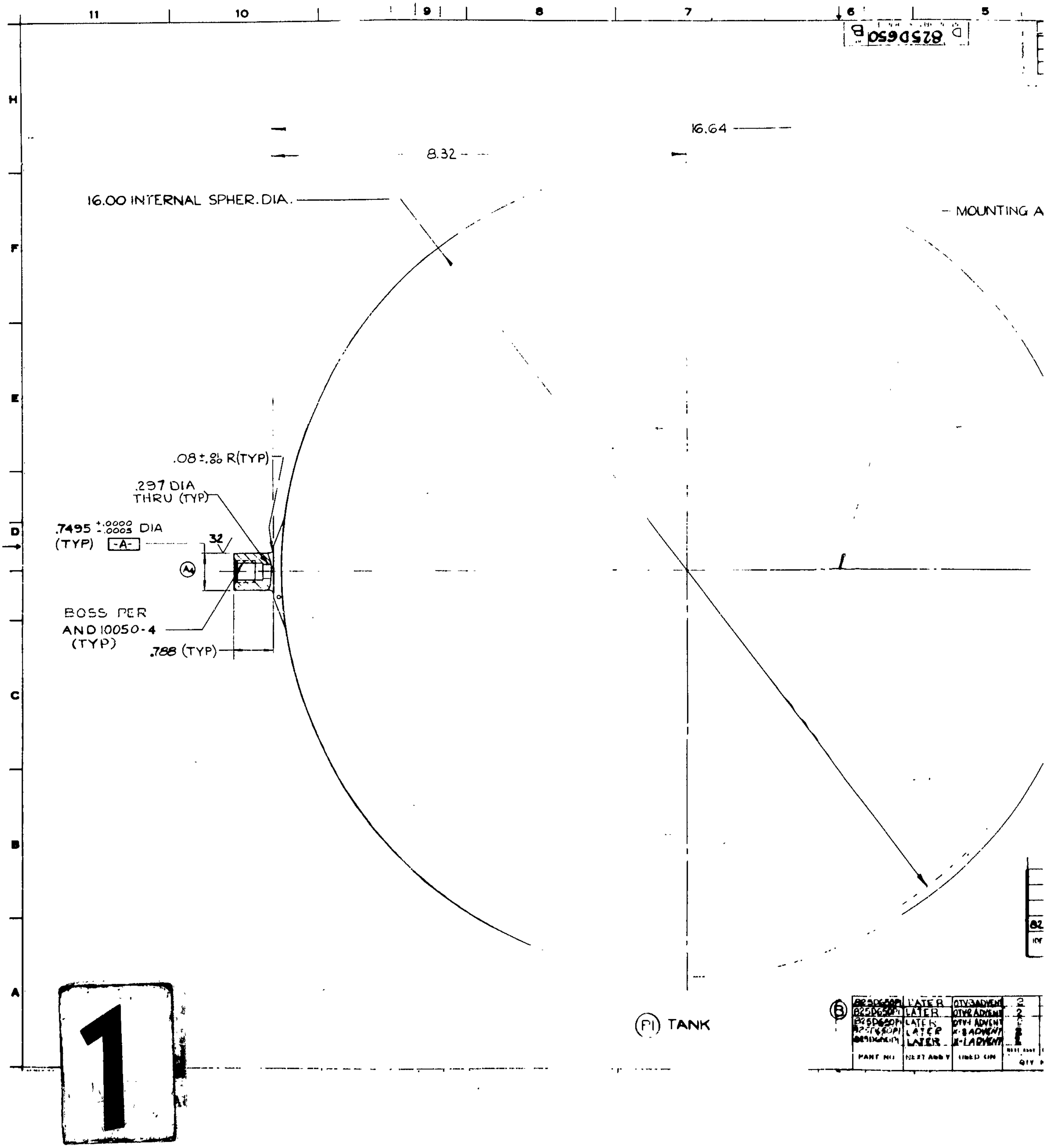


Figure 3A12. Gas Storage Tank



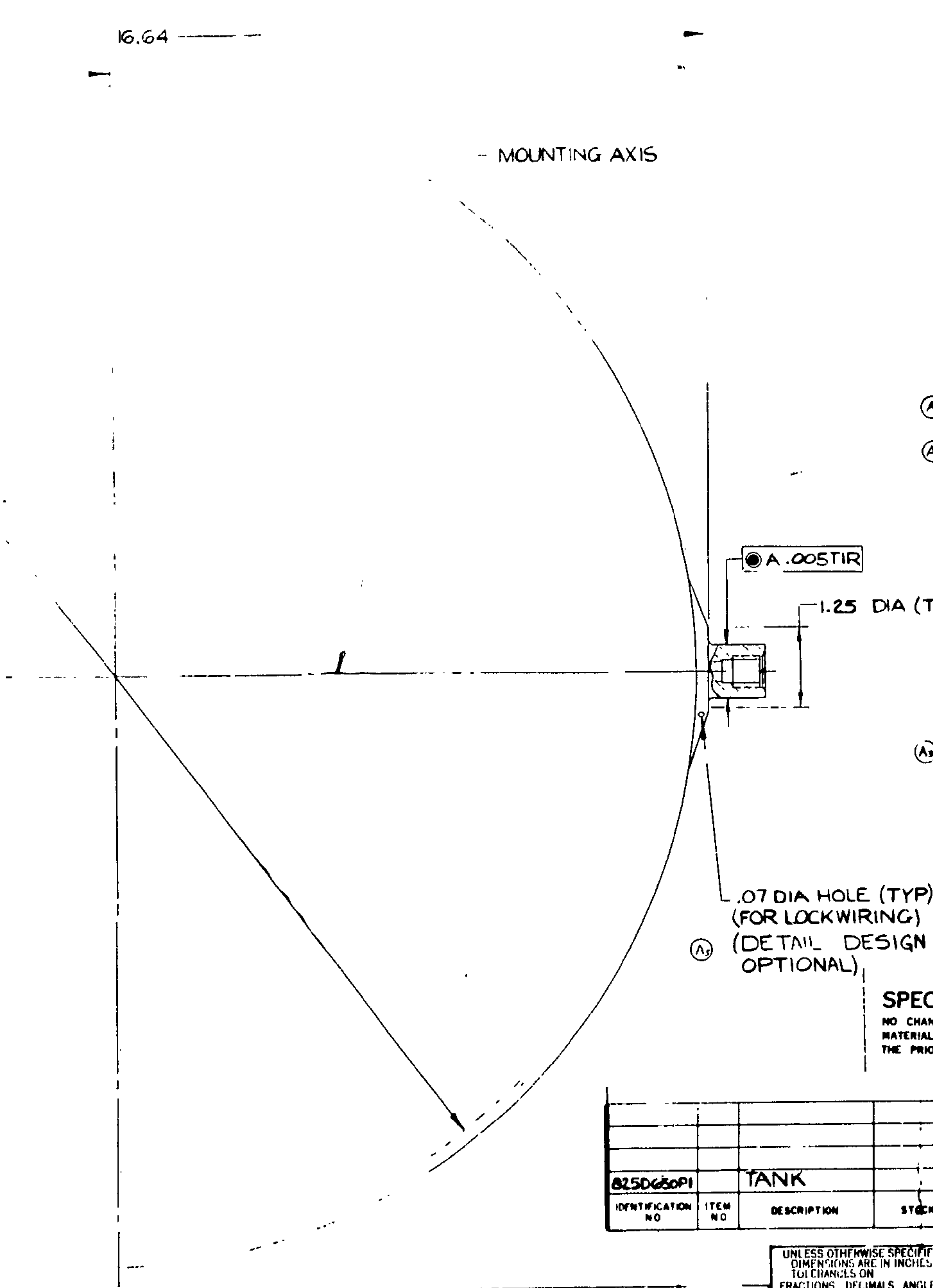
825D650 B
16.64
8.32
16.00 INTERNAL SPHER. DIA.
MOUNTING A
.08 ±.01/.00 R(TYP)
.297 DIA
THRU (TYP)
.7495 +.0000/-.0005 DIA
(TYP) -A-
32
BOSS PER
AND 10050-4
(TYP)
.788 (TYP)
(P1) TANK
LATER
PART NO
NEXT ASSY
USED ON
QTY
1

D 825D650 B

MODEL NO.	ASSY. DWG. NO.	VENDOR
SOURCE OF SUPPLY		

REVISIONS

ZONE	SYM	DESCRIPTION	DATE	APPROVAL
	A	MODIFIED TANK TRUNNIONS & CHANGED TANK PRESSURES	4/9/61	
	B		6/29/61	



GENERAL NOTES —

1. TANK TO BE IN ACCORDANCE WITH G.E. SPECIFICATION SVS-2562
2. INTERNAL VOLUME 2145 CU IN(NOM) AT OPERATING PRESSURE ± 1%, VARIES ACCORDING TO THE TOLERANCE ON THE RADIUS.
3. (A) MAX ALLOWABLE TANK WT: 19.0 LBS.
4. OPERATING TEMPERATURE RANGE: -100°F TO +160°F.
5. (A) PRESSURE: OPERATING 2530 PSI; PROOF 3795 PSI; BURST 5060 PSI
6. THE TANKS SHALL BE MARKED IN ACCORDANCE WITH G.E. DRAWING 825 D650 AND G.E. SPECIFICATION 118A1526, CLASS II, WITH THE FOLLOWING INFORMATION:
   - G.E. PART NO.
   - G.E. SERIAL NO.
   - VENDOR'S PART NO.
   - VENDOR'S SERIAL NO.
   - WEIGHT
   - OPERATING PRESSURE
   - STANDARD VOLUME
7. (A)
8. DRAWING TERMS AND TOLERANCES PER G.E. SPEC. 118A1664.
9. TANK TO BE SIMPLY SUPPORTED AT FITTING BOSSES, SUCH THAT NO BENDING RESTRAINT WILL BE IMPOSED AND LATERAL RESTRAINT ALONG MOUNTING AXIS WILL NOT EXCEED 200LB/IN.
10. ACCELERATION LOADS APPLIED SIMULTANEOUSLY WITH OPERATING PRESSURE
    - 7 G NORMAL TO MOUNTING AXIS
    - 2 G PARALLEL TO MOUNTING AXIS

SPECIFICATION CONTROL DRAWING

NO CHANGES SHALL BE MADE TO THE DESIGN, CONFIGURATION, MATERIAL, PARTS OR MANUFACTURING PROCESSES, WITHOUT THE PRIOR WRITTEN APPROVAL OF PURCHASING.

IDENTIFICATION NO	ITEM NO	DESCRIPTION	STOCK SIZE	MATERIAL	MATERIAL SPEC	FINISH SPEC	CALC UNIT WT	ZONE	ITEM REV
825D650P1		TANK		TITANIUM 6AL-4V	AMS 4928				

LIST OF MATERIAL

PART NO	NEXT ASSY	USED ON	QTY REQD		SERIAL NO
825D650P1	LATER	QTV3 ADVENT	2	2	
825D650P1	LATER	QTV2 ADVENT	2	2	
825D650P1	LATER	QTV1 ADVENT	2	2	
825D650P1	LATER	F-3 ADVENT	2	2	
825D650P1	LATER	F-1 ADVENT	2	2	

(F1) TANK

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES ± .XXX ± .005 ± 0°30' .XX ± .02 125 ALL SURFACES

DRAWN ... DATE April 14 1961 ... ENGR ... MFG ...

TANK, GAS STORAGE

GENERAL ELECTRIC MSVD PHILA, PA.

SIZE D 825D650

SCALE FULL

ADV

2

Figure 3A13. Tank, Gas Storage

APPENDIX 3B

PNEUMATIC SUBSYSTEM USING COMBINATION FLUSH AND VENT PURGING ON THE HYDROGEN AND OXYGEN SIDES SIMULTANEOUSLY

APPENDIX 3B

PNEUMATIC SUBSYSTEM USING COMBINATION FLUSH AND VENT PURGING ON THE HYDROGEN AND OXYGEN SIDES SIMULTANEOUSLY

A. Objectives

The objectives of this purge sequence, in terms of pneumatic considerations, were as follows:

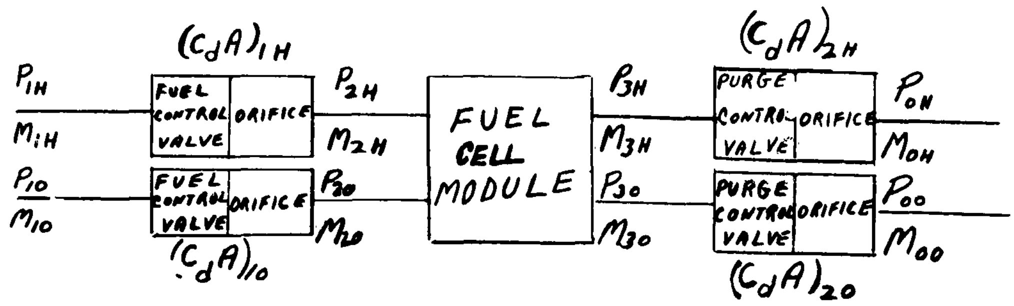
1. To replace by through flow (flush) one module volume of gas on the oxygen side in 45 seconds. (One module volume is 100 $in.^3$)
2. To reduce the pressure on the hydrogen side from 15 psia nominal to 13 psia nominal with a minimum of through flow (flush).
3. To have the nominal pressure on the oxygen side at the same pressure as on the hydrogen side after the initial transient.
4. Items 1, 2 and 3 above shall be met by simply energizing and de-energizing the two downstream purge valves simultaneously and using simple orifices upstream and downstream of the module to acquire the pressure and flow requirements.
5. Orifice sizes shall, if possible, be at least 0.015" diameter for contamination and manufacturing considerations.

B. Conclusions

1. The desired purging technique can be accomplished by simple orificing.
2. The nominal orifice diameters required for a C_d of 0.75 are:
   - a.) oxygen upstream, 0.02575"
   - b.) oxygen downstream, 0.0225"
   - c.) hydrogen upstream, 0.01026"
   - d.) hydrogen downstream. 0.008422"
3. The small orifice sizes required on the hydrogen side are undesirable.
4. Clogging of an upstream orifice would result in loss of the module.
5. Tests should be conducted using the module to verify that the orifices are basically correct and to optimize their characteristics for variations in actual hardware from that of the test set-up.

C, Orifice Sizing Analysis

The pneumatic subsystem with the fuel module may be depicted as follows for the purposes of this analysis:



The relation for flow is

$$M = C_d A_o \frac{P_u}{\sqrt{RT}} \sqrt{2g \, \frac{\frac{K}{K-1}\left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}\right]}{1-\left(\frac{A_o}{A_u}\right)^2 \left(\frac{P_d}{P_u}\right)^{2/K}}}$$

where

M = mass flow - lb/sec.
C_d = discharge coefficient - dimensionless.
A_o = orifice diameter - in.^{2}.
P_u = upstream pressure - lb/in.^{2} abs.
R = gas constant - ft-lb/lb-°R - 12R in/°R.
T = inlet temperature - °R.
g = gravity acceleration - 32.2 ft/sec^2 - 386.4 in./sec^2.
K = adiabatic exponent - dimensionless.
P_d = downstream pressure - lb/in.^{2} abs..
A_u = inlet tube area - in.^{2}.

When A_u is at least ten times that of A_o, the quantity $1-\left(\frac{A_o}{A_u}\right)^2\left(\frac{P_d}{P_u}\right)^{2/K}$ may be neglected. For choked flow the equation for flow becomes

$$M = C_d A_o \frac{P_u}{\sqrt{RT}} \sqrt{2g \, \frac{K}{K+1} \left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}}$$

Oxygen Side

The flow of gas to replace 100 in.^{3} in 45 seconds assuming a temperature of 68^oF and a pressure of 13 lb/in.^{2} would be

$$\frac{W}{t} = \frac{PV}{RTt} = \frac{13 \text{ lb/in}^2 \times 100 \text{ in}^3}{48.3 \times 12 \frac{\text{in}}{^oR} \times 528\ ^oR \times 45 \text{ sec}} = 94.25 \times 10^{-6} \text{ lb/sec}$$

where R = 48.3 x 12 $^{in}/^oR$ for oxygen. The flow required to maintain full electrical load will be as follows. Using the Polymer A-Prime data where E = 0.87 volts, the oxygen required is 0.765 ^{lb}/KW-Hr. For a load of 25 watts this results in a flow of

$$0.765 \text{ lb/KW-Hr.} \times \frac{25}{1000} \text{ KW} \times \frac{1}{3600} \frac{\text{Hr.}}{\text{Sec}} = 5.312 \times 10^{-6} \text{ lb/sec.}$$

In addition, there will be a flow out of the module associated with the decrease in pressure from 15 to 13 psia; however, this does not enter into the steady state flow analysis.

The C_dA for the upstream orifice is

$$C_d A = \frac{M}{P_u \sqrt{\frac{2g}{RT} \frac{K}{K-1} \left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}} \right]}}$$

where

$M = 99.56 \times 10^{-6}$ ^{lb}/sec
$P_u = 15$ ^{lb}/in.^{2}
$g = 32.2 \times 12$ $^{in.}$/sec^2
$R = 48.3 \times 12$ $^{in.}/^oR$
$T = 528^oR$
$K = 1.40$
$P_d = 13$ ^{lb}/in.^{2}

$$C_dA = 3.906 \times 10^{-4}\ in^2$$

The C_dA for the downstream orifice is

$$C_dA = \frac{M}{P_u \sqrt{\frac{2g}{RT}\frac{K}{K+1}\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}}}$$

where

$M = 94.25 \times 10^{-6}$ lb/sec.
$P_u = 13$ lb/in^2
$g = 32.2 \times 12$ in./sec.
$R = 48.3 \times 12$ in./^oR
$T = 528^oR$
$K = 1.40$

$$C_dA = 2.98 \times 10^{-4}\ in.^2$$

Hydrogen Side

The flow required to maintain full electrical load will be as follows. Using the Polymer A - Prime data where E = .87 volts, the hydrogen required is .0955 lb/KW-hr. For a load of 25 watts this results in a flow of

$$0.0955\ lb/KW\text{-}hr \times \frac{25}{1000} KW \times \frac{1}{3600}\frac{hr}{sec} = 0.663 \times 10^{-6} lb/sec$$

It was decided to use a steady state purge flow of 5 times the load flow or an inlet gas flow of 6 times normal full load flow to minimize drying of the membranes

In addition, there is a flow out of the module as a result of the decrease in pressure from 15 to 13 psia; however, this flow does not enter into the steady state analysis.

The C_dA for the upstream orifice is

$$C_dA = \frac{M}{P_u \sqrt{\frac{2g}{RT}\frac{K}{K-1}\left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}\right]}}$$

where

$M = 6 \times .663 \times 10^{-6} = 3.978 \times 10^{-6}$ lb/sec
$P_u = 15$ lb/in.^{2}

$g = 32.2\text{x}12 \,\text{in./sec}^2$
$R = 767\text{x}12 \,\text{in}/^\circ\text{R}$
$T = 528^\circ\text{R}$
$K = 1.40$
$P_d = 13 \,\text{lb/in.}^2$

$$C_d A = .6815 \times 10^{-4} \,\text{in}^2$$

The C_dA for the downstream orifice is

$$C_d A = \frac{M}{P_v \sqrt{\frac{2g}{RT} \frac{K}{K+1} \left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}}}$$

where $M = 5\text{x}.663\text{x}10^{-6} = 3.315\text{x}10^{-6}$

$$C_d A = .41178 \times 10^{-4} \,\text{in}^2$$

This results in orifice sizes as follows for a C_d of 0.75.

Oxygen upstream

$$d = .02575 \,\text{in.}$$

Oxygen downstream

$$d = .0225 \,\text{in.}$$

Hydrogen upstream

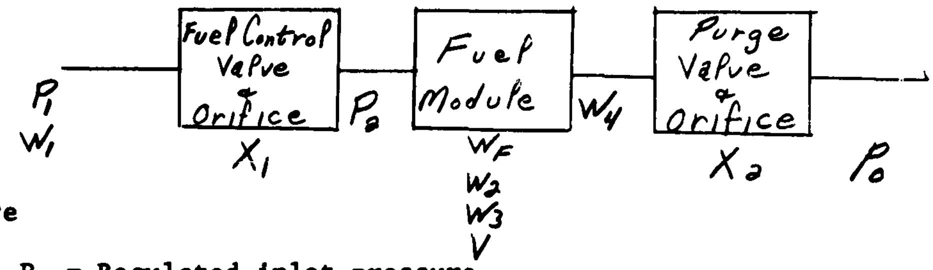
$$d = .01026 \,\text{in.}$$

Hydrogen downstream

$$d = .008422 \,\text{in.}$$

D. Transient Response Analysis

The subsystem may be depicted as follows for the purposes of this analysis.



where

P_1 = Regulated inlet pressure.

W_1 = Flow into the Fuel Control Valve and Orifice Assembly.

X_1 = Resistance to flow in the Fuel Control and Orifice Assembly.

P_2 = Pressure in the Fuel Module

W_F = Flow used in the module for conversion to electrical energy.

W_2 = Flow W_1 minus flow W_F.

W_3 = Flow from V due to decrease in P_2 pressure.

W_4 = Flow into the Purge Valve and Orifice Assembly.

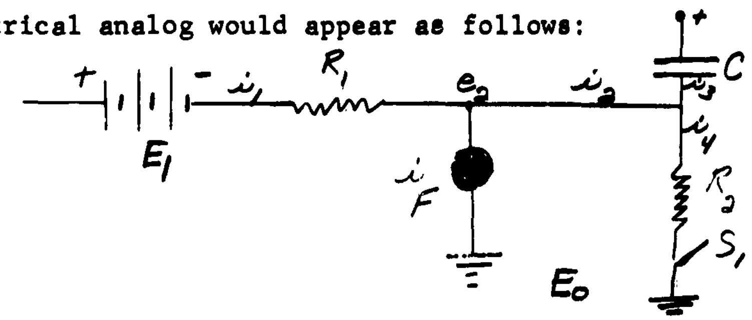
V = Volume of the module and lines from X_1 to X_2.

X_2 = Resistance in flow in the Purge Valve and Orifice Assembly.

P_o = Outlet pressure.

To be better able to analyze the transient response of the subsystem to purge valve actuating, the electrical analog will be studied.

The electrical analog would appear as follows:



As the desired parameter is the pressure in the module, the analysis will be aimed at obtaining a relation for e_2 as a function of time.

$$i_1 = i_2 + i_F = \frac{E_1 - e_2}{R_1}$$

$$i_4 = i_2 + i_3 = \frac{e_2 - E_0}{R_2}$$

$$i_3 = \frac{e_{2_0} - e_{2_f}}{\frac{R_2 R_1}{R_1 + R_2}} e^{-\frac{t}{\frac{R_1 R_2 C}{R_1 + R_2}}}$$

$$i_F - i_3 = \frac{E_1 - e_2}{R_1} - \frac{e_2 - E_0}{R_2}$$

$$e_2 \left(\frac{R_1 + R_2}{R_1 R_2}\right) = \frac{(E_1 - R_1 i_F)}{R_1 + R_2} R_2 + \frac{(e_{2_0} - e_{2_f})(R_1 + R_2)}{R_1 + R_2} e^{-\frac{t}{\frac{R_1 R_2 C}{R_1 + R_2}}} + \frac{E_0 R_1}{R_1 + R_2}$$

For $E_0 = 0$

$$e_2 = \frac{(E_1 - R_1 i_F) R_2}{R_1 + R_2} + (e_{2_0} - e_{2_f}) e^{-\frac{t}{\frac{R_1 R_2 C}{R_1 + R_2}}}$$

When $t = 0$, $e^{-\frac{t}{\frac{R_1 R_2 C}{R_1 + R_2}}} = 1$ and $e_2 = E_1 - i_F R_1$

$$e_{2_0} - e_{2_f} = (E_1 - i_F R_1) - \frac{(E_1 - R_1 i_F) R_2}{R_1 + R_2}$$

$$e_2 = \frac{E_1 - R_1 i_E}{R_1 + R_2} \left(R_2 + R_1 e^{-\frac{t}{\frac{R_1 R_2 C}{R_1 + R_2}}} \right)$$

The units for the pneumatic and electrical systems are as follows:

Flow:

i = amperes = coulombs/sec.

w = standard cubic feet/sec.

Pressure:

E, e = volts

P = lb/in.^{2} abs.

Volume:

C = farads

V = cubic feet x $\frac{1}{14.7\ lb/in^2} \times \frac{528^\circ R}{T\ ^\circ R} \times \frac{14.7\ lb/in^2}{P\ lb/in^2} = SCF/lb/in^2$

Resistance to flow:

R = ohms = $\frac{\text{volts (Voltage Drop)}}{\text{coulomb/sec.}}$

X = $\frac{\text{lb/in}^2 \text{ (pressure drop)}}{\text{SCF/sec.}}$

For the fuel control valve and orifice the volume flow is

$$w_1 = C_{d_1} A_1 P_1 \sqrt{\frac{2g}{RT_1}} \sqrt{\frac{K}{K-1}\left[\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}\right]}\ V_s$$

where V_s = specific volume at standard conditions.

For which

$$X_1 = \frac{P_1 - P_2}{V_s C_{d_1} A_1 P_1 \sqrt{\frac{2g}{RT_1}} \sqrt{\frac{K}{K-1}\left[\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}\right]}}$$

$$= \frac{lb/in.^2}{ft^3/lb \times in.^2 \times lb/in.^2 \sqrt{\frac{in/sec^2}{in/{}^\circ R \times {}^\circ R}}} = \frac{1}{ft^3/lb \times in.^2 \sqrt{\frac{1}{sec^2}}} = \frac{lb/in.^2}{ft^3/sec}$$

For the purge valve and orifice assembly which is choked

$$W_2 = C_{d_2} A_2 P_2 \sqrt{\frac{2g}{RT_2}} \sqrt{\frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]} V_S$$

For which

$$X_2 = \frac{P_2}{V_S C_{d_2} A_2 P_2 \sqrt{\frac{2g}{RT_2}} \sqrt{\frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]}}$$

In pneumatic terms the transient response is

$$P_2 = \frac{P_1 - X_1 W_F}{X_1 + X_2}\left(X_2 + X_1 e^{-\frac{\frac{t}{X_1 X_2 V}}{X_1 + X_2}}\right)$$

where

$$\frac{X_1}{X_2} = \frac{\dfrac{P_1 - P_2}{V_S C_{d_1} A_1 P_1 \sqrt{\frac{2g}{RT}} \sqrt{\frac{K}{K-1}} \sqrt{\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}}}}{\dfrac{1}{V_S C_{d_2} A_2 \sqrt{\frac{2g}{RT}} \sqrt{\frac{K}{K-1}} \sqrt{\left(\frac{2}{K+1}\right)^{2/K-1} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}}}$$

for K = 1.4 (hydrogen and oxygen)

$$X_1 = \frac{P_1 - P_2}{P_1} \quad \frac{\sqrt{R}}{2.264\, V_S C_{d_1} A_1 \sqrt{\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}}}$$

$$X_2 = \frac{\sqrt{R}}{V_S C_{d_2} A_2 \; 2.264 \times .2588}$$

$$P_2 = (15 - X_1 W_F)\frac{1 + \frac{X_1}{X_2} e^{-\frac{\frac{t}{X_1 X_2 V}}{X_1 + X_2}}}{1 + \frac{X_1}{X_2}}$$

for $P_1 = 15$ lb/in.^{2}

For the oxygen system

$$W_F = m_F V_S$$

$$= 5.312 \times 10^{-6}\ \text{lb/sec} \times 11.2\ \text{ft}^3/\text{lb} @ 32°F \times \frac{528\ °R}{492\ °R}$$

$$= .00006385\ \text{SCF/sec}$$

$$X_1 = \frac{P_1 - P_2}{P_1} \qquad \frac{\sqrt{R}}{2.264\, V_S C_{d_1} A_1 \sqrt{\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}}}$$

where $P_1 = 15\ \text{lb/in}^2$
$P_2 = 13\ \text{lb/in}^2$
$R = 48.3 \times 12\ \text{in}/°R$
$V_3 = 11.2 \times \frac{528}{492}\ \text{SCF/lb}$
$C_{d_1} = 3.906 \times 10^{-4}\ \text{in}^2$
$K = 1.40$

$$X_2 = \frac{1.706\sqrt{R}}{V_S C_{d_2} A_2}$$

where $C_{d_2}A_2 = 2.98 \times 10^{-4}\ \text{in.}^2$

$$X_2 = \frac{1.706 \times 24.1}{11.2 \times \frac{528}{492} \times 2.98 \times 10^{-4}}$$

$$= 11563$$

For $V = 100\ \text{in.}^3 \times \frac{1}{14.7\text{x}1728}\ \text{SCF}/\text{lb}/\text{in}^2$ (Water tank full)

$$P_2 = (15 - 16.70 \times .00006385)\,\frac{1 + \frac{1670}{11563}\, e^{-\frac{t}{\frac{1670 \times 11563}{1670 + 11563} \times \frac{100}{15 \times 1728}}}}{1 + \frac{1670}{11563}}$$

$$= 13.01 + 1.88\, e^{-\frac{t}{5.625}}$$

For $V = 250\ \text{in.}^3 \times \frac{1}{15\text{x}1728}\ \text{SCF}/\text{lb}/\text{in.}^2$ (Water tank empty)

$$P_2 = 13.01 + 1.88\, e^{-\frac{t}{14.05}}$$

For the hydrogen system

$$W_F = m_F V_S$$

$$= .663 \times 10^{-6}\ \text{lb/sec} \times 178\ \text{ft}^3/\text{lb} @ 32°F \times \frac{528°R}{492°R}$$

$$= .0001267\ \text{SCF/sec}$$

$$X_1 = \frac{P_1 - P_2}{P_1} \quad \frac{\sqrt{R}}{2.264 V_s C_{d_1} A_1 \sqrt{\left(\frac{P_2}{P_1}\right)^{2/K} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}}}}$$

where

$P_1 = 15 \ \text{lb/in.}^2$

$P_2 = 13 \ \text{lb/in.}^2$

$R = 767 \times 12 \ \text{in./}^\circ\text{R}$

$V_s = 178 \times \frac{528}{492} \ \text{SCF/lb.}$

$C_{d_1}A_1 = .6215 \times 10^{-4} \ \text{in.}^2$

$K = 1.40$

$$X_1 = \frac{15-13}{15} \quad \frac{\sqrt{767 \times 12}}{2.264 \times 178 \times \frac{528}{492} \times .6215 \times 10^{-4} \times .1809}$$

$$= 2628$$

$$X_2 = \frac{1.706 \sqrt{R}}{V_s C_{d_2} A_2}$$

where $C_{d_2}A_2 = .4178 \times 10^{-4} \ \text{in.}^2$

$$X_2 = \frac{1.706 \times 95.87}{178 \times \frac{528}{492} \times .4178 \times 10^{-4}}$$

$$= 20475$$

For $V = 25 \ \text{in.}^3 \times \frac{1}{15 \times 1728} \ \text{SCF/lb./in.}^2$ (one module volume)

$$p_2 = (15 - 2628 \times .0001267) \ \frac{1 + \frac{2628}{20475} e^{-\frac{t}{\frac{2628 \times 20475}{2628 + 20475} \times \frac{25}{15 \times 1728}}}}{1 + \frac{2628}{20475}}$$

$$= 13.00 + 1.667 \, e^{-\frac{t}{2245}}$$

E. Test and Test Analysis

All testing was planned and conducted with nitrogen gas.

The test orifices were made by pressing a brass insert into an AN815-4C union and subsequently drilling a hole in the brass insert. As the C_d of the orifice could not be predicted accurately and to avoid calculation inaccuracies the orifices were sized to obtain the desired flow for the specified pressure drop. To do this, it was necessary to determine the nitrogen flow for the respective hydrogen and oxygen flows. A volume flow meter was used, therefore volume flows had to be calculated.

Study of the flow equations shows that the oxygen and hydrogen flows in lb/sec must be multiplied by the ratio of the $\sqrt{R}$ for oxygen or hydrogen to the $\sqrt{R}$ for nitrogen and by the specific volume of nitrogen to get SCFM. Thus the flows in SCFM of nitrogen required are:

Oxygen upstream

$$99.56 \times 10^{-6}\ \text{lb/sec}\ \sqrt{\frac{48.3 \times 12}{55.2 \times 12}} \times 12.8\ \text{ft}^3/\text{lb} @ 32^\circ F \times \frac{528^\circ R}{492^\circ R} \times 60\ \frac{\text{sec}}{\text{min}}$$

$.07683$ SCFM

Oxygen downstream

$$.07683\ \text{SCFM} \times \frac{94.25}{99.56} = .07277\ \text{SCFM}$$

Hydrogen upstream

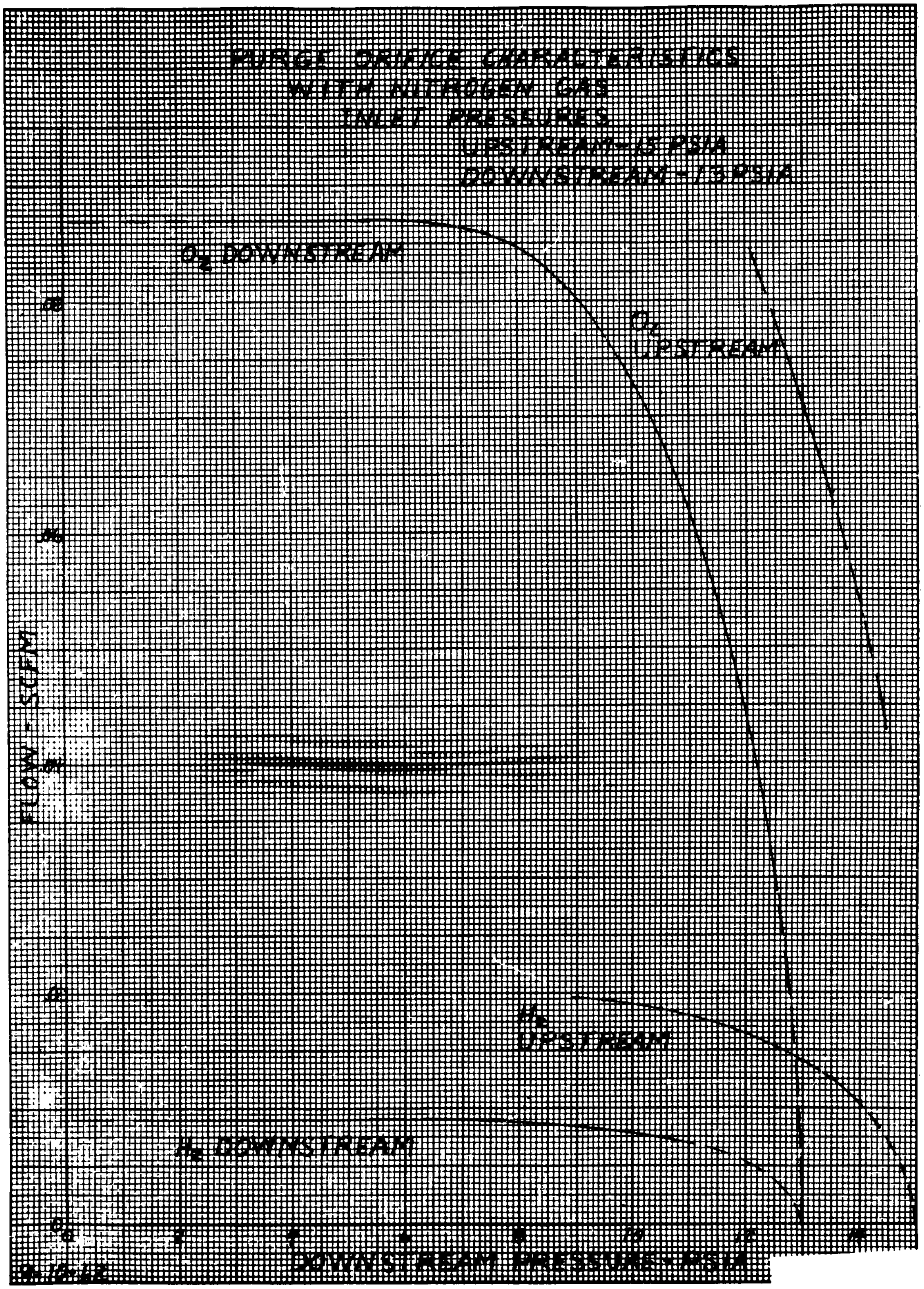
$$3.978 \times 10^{-6}\ \text{lb/sec}\ \sqrt{\frac{767 \times 12}{55.2 \times 12}} \times 12.8\ \text{ft}^3/\text{lb} @ 32^\circ F \times \frac{528^\circ R}{492^\circ R} \times 60\ \frac{\text{sec}}{\text{min}}$$

$.01224$ SCFM

Hydrogen downstream

$$.01224\ \text{SCFM} \times \frac{3.315}{3.978} = .01021\ \text{SCFM}$$

After having made the orifices, flow versus pressure drop tests were conducted. The results are plotted on Figure 3B-1. At the points of prime concern the flows are as follows:



PURGE ORIFICE CHARACTERISTICS
WITH NITROGEN GAS
INLET PRESSURES
UPSTREAM-15 PSIA
DOWNSTREAM - 13 PSIA
O_2 DOWNSTREAM
O_2 UPSTREAM
H_2 UPSTREAM
H_2 DOWNSTREAM
FLOW - SCFM
DOWNSTREAM PRESSURE - PSIA

Figure 3B-1

	Inlet Press psia	Outlet Press psia	Flow SCF
O_2 upstream	15	13	.07075
O_2 downstream	13	less than 1	.087
H_2 upstream	15	13	.01407
H_2 downstream	13	less than 1	.0088

The actual effective areas would than be the calculated effective area times the ratio of the actual flow to the flow used in the calculation or

Oxygen upstream

$$3.906 \times 10^{-4} \text{ in.}^2 \times \frac{.07075}{.07683} = 3.597 \times 10^{-4} \text{ in.}^2$$

Oxygen downstream

$$2.98 \times 10^{-4} \text{ in.}^2 \times \frac{.087}{.07277} = 3.566 \times 10^{-4} \text{ in.}^2$$

Hydrogen upstream

$$.6215 \times 10^{-4} \text{ in.}^2 \times \frac{.01407}{.01224} = .714 \times 10^{-4} \text{ in.}^2$$

Hydrogen downstream

$$.4178 \times 10^{-4} \text{ in.}^2 \times \frac{.0088}{.01021} = .361 \times 10^{-4} \text{ in.}^2$$

To determine the transient pressure decay for the actual orifice sizes the respective values of X (resistance to flow) must be determined along with considerations for the use of nitrogen

First it is necessary to determine the steady state value of the simulated module pressure in order to determine X_1.

The upstream orifice flow M_u minus the downstream orifice flow M_d, is equal to the gas consumed in the module which was simulated during test with bleed flow.

$$m_v - m_d = 5.312 \times 10^{-6} \text{ lb/sec. of } O_2$$

$$m_v = C_d A_v P_v \sqrt{\frac{2g}{RT}\,\frac{K}{K-1}\left[\left(\frac{P_d}{P_v}\right)^{2/K} - \left(\frac{P_d}{P_v}\right)^{\frac{K+1}{K}}\right]}$$

$$m_d = C_d A_d P_d \sqrt{\frac{2g}{RT}\,\frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]}$$

$$C_d A_v P_v \sqrt{\frac{2g}{RT}\,\frac{K}{K-1}}\sqrt{\left(\frac{P_d}{P_v}\right)^{2/K} - \left(\frac{P_d}{P_v}\right)^{\frac{K+1}{K}}} - C_d A_d P_d \sqrt{\frac{2g}{RT}\,\frac{K}{K-1}}$$

$$\sqrt{\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}} = 5.312 \times 10^{-6}\sqrt{\frac{48.3}{55.2}}$$

$$3.597 \times 15 \times 2.264\sqrt{\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}} - 3.566\,P_d \times 2.264 \times .2589$$

$$= .053122\sqrt{\frac{48.3}{55.2}}$$

$$58.33\sqrt{\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}} = P_d + .02374$$

Solving by trial and error.

P_d	$\left(\frac{P_d}{15}\right)^{1.428}$	$\left(\frac{P_d}{15}\right)^{1.714}$	$\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}$	$58.33\sqrt{\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}}$	$P_d + .02374$
13	.8155	.7828	.0327	10.553	13.02374
12	.7272	.6825	.0447	12.335	12.02374
12.2	.7432	.701	.0422	11.98	12.22374
12.1	.736	.6922	.0438	12.22	12.12374
12.13	.7373	.6937	.0436	12.17	12.15374

Use 12.13 psia for P_d

The values can now be determined to obtain a relation for the transient pressure decay.

$$X_1 = \frac{15-12.13}{15} \quad \frac{\sqrt{55.2 \times 12}}{2.264 \times 12.8 \times \frac{528}{492} \times 3.597 \times 10^{-4} \times .2088}$$

$$= 2108$$

$$X_2 = \frac{1.706 \sqrt{55.2 \times 12}}{12.8 \times \frac{528}{492} \times 3.566 \times 10^{-4}}$$

$$= 8960$$

$$W_F = M_F V_S$$

$$= 5.312 \times 10^{-6} \text{ lb/sec} \sqrt{\frac{48.3 \times 12}{55.2 \times 12}} \times 12.8 \text{ ft.}^3/\text{lb} \text{ @ } 32°F \times \frac{528}{492}$$

$$= .0000684 \text{ SCF/sec.}$$

$$p_2 = (15 - X_1 W_F) \frac{1 + \frac{X_1}{X_2} e^{-\frac{t}{\frac{X_1 X_2 V}{X_1 + X_2}}}}{1 + \frac{X_1}{X_2}}$$

$$= (15 - 2108 \times .0000684) \frac{1 + \frac{2108}{8960} e^{-\frac{t}{\frac{2108 \times 8960}{11068} \times \frac{100}{15 \times 1728}}}}{1 + \frac{2108}{8960}}$$

$$= 12.03 + 2.826\, e^{-\frac{t}{6.72}}$$

$$\text{for } V = 100\ in.^3 \times \frac{1}{15 \times 1728}\ SCF/sec$$

$$P_2 \quad = 12.03 + 2.826\, e^{-\frac{t}{17.46}}$$

for $V = 260\ in^3 \times \frac{1}{15 \times 1728}\ SCF/sec$ ($260\ in^3$ instead of 250 in.^{3} tank was used for expediency.)

Hydrogen Side

First it is necessary to determine the steady state value of the simulated fuel module pressure in order to determine X_1.

The upstream orifice flow, M_u, minus the downstream orifice flow, M_d, is equal to the gas consumed in the module which was simulated during test with bleed flow.

$$M_u - M_d = .663 \times 10^{-6}\ lb/sec\ of\ H_2$$

$$M_u = C_d A_u P_u \sqrt{\frac{2g}{RT}\ \frac{K}{K-1}\left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}\right]}$$

$$M_d = C_d A_d P_d \sqrt{\frac{2g}{RT}\ \frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{2/K-1} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]}$$

$$C_d A_u P_u \sqrt{\frac{2g}{RT}\frac{K}{K-1}} \sqrt{\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}} - C_d A_d P_d \sqrt{\frac{2g}{RT}\frac{K}{K-1}} \sqrt{\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

$$= .663\times10^{-6}\sqrt{\frac{262}{55.2}}$$

$$.714 \times 15 \times 2.264 \sqrt{\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}} = .361 \times P_d \times 2.264 \times .2589 + .00663 \times 3.726$$

$$114.6\sqrt{\left(\frac{P_d}{15}\right)^{1.428} - \left(\frac{P_d}{15}\right)^{1.714}} = P_d + .1167$$

Solving by trial and error.

P_d	$(\frac{P_d}{15})^{1.428}$	$(\frac{P_d}{15})^{1.714}$	$(\frac{P_d}{15})^{1.428} - (\frac{P_d}{15})^{1.714}$	$114.6\sqrt{(\frac{P_d}{15})^{1.428} - (\frac{P_d}{15})^{1.714}}$	$P_d+.1167$
13	.8155	.7828	.0327	20.72	13.1167
14	.9061	.8885	.0176	15.21	14.1167

This indicates that the pressure in the simulated module should be in excess of 14 psia; however, this was not the case in the test. Since the analytical and test values correlate poorly in this respect, a satisfactory calculation of the transient pressure decay would not be feasible. The poor correlation is thought to be due to variations when using the small orifice diameters and inaccuracies at the low flows associated with this hydrogen system.

The tests were conducted using a tank to simulate the fuel module and with a pressure transducer for obtaining a transient recording of the pressure between the upstream and downstream orifices. The pressure transients obtained in test and the calculated transient are tabulated on Table 3B-1 and are shown on Figure 3B-2 for opening of the purge valves. The test was conducted using the fuel cell program pressure regulator; thus, the difference from the nominal pressure prior to actuating the purge valve.

TABLE 3B-1

PRESSURE - PSIA

TIME-SECONDS	O_2(100 in.^{3})		O_2(260 in.^{3})		H_2
	TEST	THEOR.	TEST	THEOR.	TEST
0	15.16	14.856	15.26	14.856	15.04
0.5	14.82				14.94
1	14.56	14.454	15.11	14.698	14.79
1.5	14.46				14.75
2	14.32	14.128	14.82	14.554	14.75
2.5	14.17				14.69
3	14.02	13.882	14.71	14.412	14.65
3.5	13.92				14.59
4	13.87	13.586	14.61	14.278	14.59
4.5	13.725				
5	13.63	13.3735	14.515	14.154	14.535
5.5	13.53				
6	13.47	13.1865	14.42	14.036	14.45
6.5	13.43				
7	13.335				14.39
7.5	13.275				
8	13.235	12.889	14.17	13.817	14.25
9	13.13				
10	13.08	12.669	14.065	13.625	14.20
11	12.98				
12	12.98	12.5033	13.93	13.451	14.10
14	12.74	12.3815	13.83	13.297	14.05
16	12.64	12.2907	13.73	13.16	14.05
18	12.565	12.2241		13.036	14.00
19			13.63		
20	12.49	12.1743		12.929	13.95
22	12.49		13.47		13.85
24	12.34	12.1097		12.745	13.75
25			13.335		
26	12.34				
27					13.75
28	12.24	12.07378	13.18	12.5983	
30					13.75
32		12.05407	13.08	12.4817	
33					13.725
36			13.01	12.3896	13.70
40			12.91	12.316	
44			12.835	12.2568	
50			12.69		
56			12.60		
62			12.54		
68			12.51		
74			12.49		

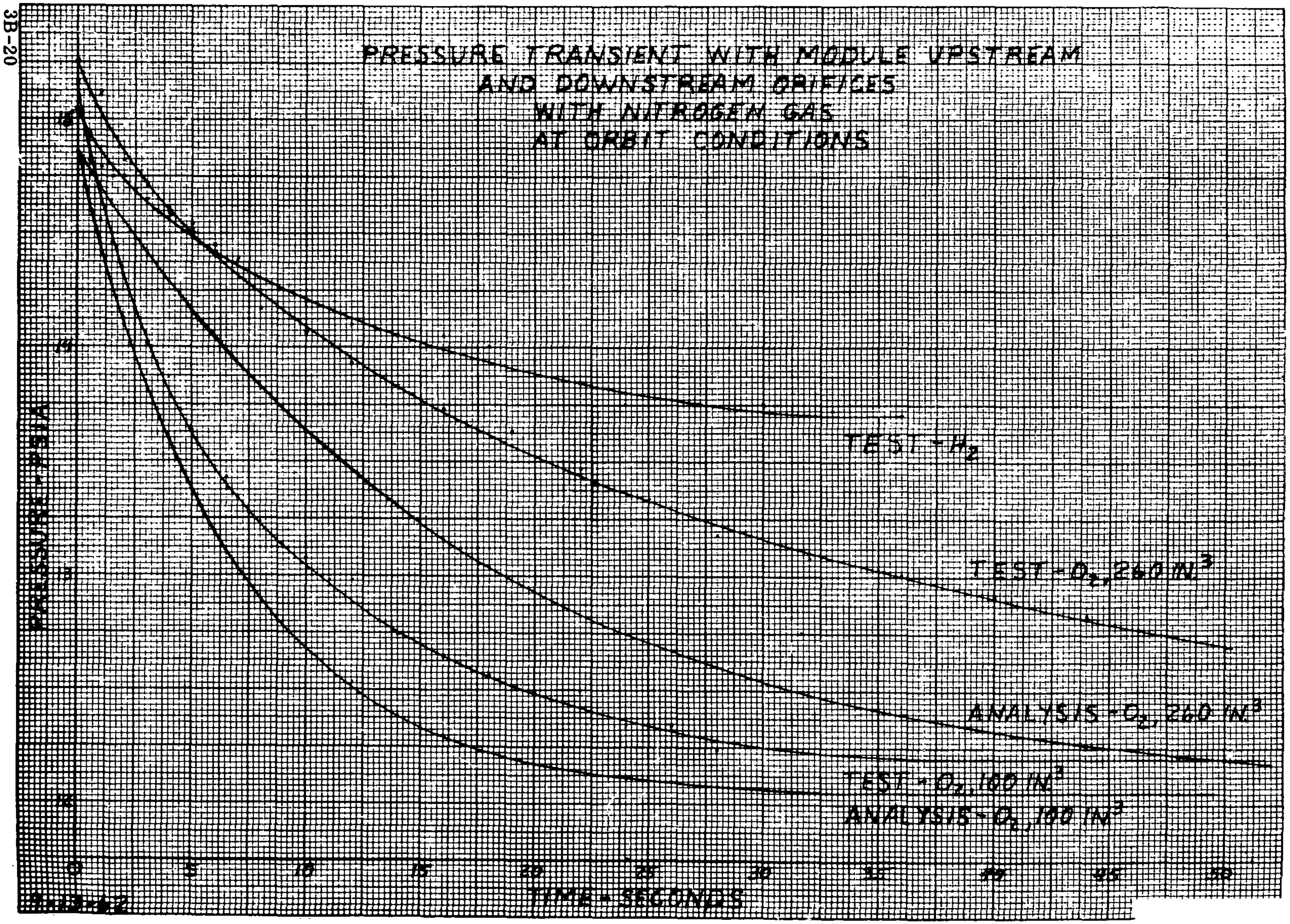

PRESSURE TRANSIENT WITH MODULE UPSTREAM
AND DOWNSTREAM ORIFICES
WITH NITROGEN GAS
AT ORBIT CONDITIONS
TEST - H_2
TEST - O_2, 260 IN^3
ANALYSIS - O_2, 260 IN^3
TEST - O_2, 100 IN^3
ANALYSIS - O_2, 100 IN^3
PRESSURE - PSIA
TIME - SECONDS
0
5
10
15
20
25
30

Figure 3B-2

APPENDIX 3C

PNEUMATIC SUBSYSTEM USING FLUSH PURGING ON THE OXYGEN SIDE AND VENT PURGING ON THE HYDROGEN SIDE

APPENDIX 3C

PNEUMATIC SUBSYSTEM USING FLUSH PURGING ON THE OXYGEN SIDE AND VENT PURGING ON THE HYDROGEN SIDE

A. Objectives

The objectives of this purge sequence in terms of pneumatic considerations are as follows:

1. To replace by "through flow" (flush) one module volume of gas on the oxygen side in 45 seconds with less than 0.5 psi drop from the normal operating pressure of 15 ± 0.5 psia. (One module volume is 91.6 in.^{3}. This is 8.4 in.^{3} less than that used in Appendix 3B due to additional information from DECO.)
2. To reduce the pressure on the hydrogen side from 15 psia nominal to 13 psia nominal within several seconds and then restoring the 15 psia with no supply flow during the purging.
3. Orifice sizes shall, if possible, be at least 0.015" diameter for contamination and manufacturing considerations.
4. The flow rates and pressures shall be accomplished with an orifice on the outlet of each of the four downstream purge valves.

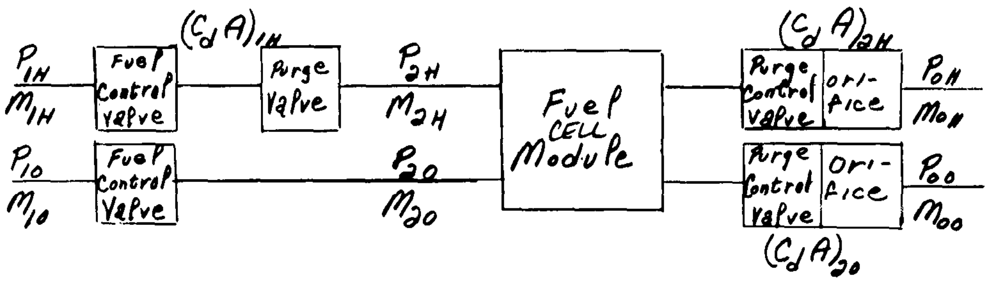
B. Conclusions

1. The desired purging technique can be accomplished by the six purge valves, two upstream and four downstream, and four orifices, one on each downstream purge valve.
2. The nominal orifice diameter required for a $C_d = .60$ for the fuel control valve is 0.0398". The equivalent Sharp Edge Orifice Diameter (ESEOD) has been changed from 0.030" to 0.040" to accomodate this.
3. The nominal orifice diameter required for a C_d of 0.75 for the oxygen side is 0.02152".
4. The nominal orifice diameter required for a C_d of 0.75 for the hydrogen side is 0.01611" for a purge time of 0.75 seconds.
5. A response time of 0.020 seconds has been requested for the purge valves so as not to have the solenoid valve response time be a significant factor.
6. During purging at sea level static conditions rather than at orbit conditions, 14.7 psia rather than 0 psia, the pressure on the hydrogen side will decrease approximately 4 psi rather than the 2 psi and the pressure on the oxygen side will decrease 1.0 psi rather than 0.5 psi as at orbit conditions. The flows will of course be higher at sea level conditions.

7. Tests should be conducted using the module to verify that the orifices are basically correct and to optimize their characteristics for variations in actual hardware from that of the test set-up.

C. Orifice Sizing Analysis

The pneumatic subsystem with the fuel module may be depicted as follows for the purposes of this analysis.



The relation for flow is

$$M = C_d A_o \frac{P_u}{\sqrt{RT}} \sqrt{2g \, \frac{\frac{K}{K-1}\left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}\right]}{1-\left(\frac{A_o}{A_u}\right)^2 \left(\frac{P_d}{P_u}\right)^{2/K}}}$$

where

M = mass flow - lb/sec.
C_d = discharge coefficient - dimensionless.
A_o = orifice diameter - in.^{2}
P_u = upstream pressure - lb/in.^{2} abs.
R = gas constant - ft. lb/lb ^oR - 12 R in/^oR.
T = Inlet temperature - ^oR.
g = gravity acceleration - 32.2 ft/sec^2 - 386.4 in/sec.
K = adiabatic exponent - dimensionless.
P_d = downstream pressure - lb/in.^{2} abs.
A_u = inlet tube area - in.^{2}.

When A_u is at least 10 times that of A_o, the quantity $1 - \left(\frac{A_o}{A_u}\right)^2 \left(\frac{P_d}{P_u}\right)^{2/K}$ may be neglected. For choked flow the equation for flow becomes

$$M = C_d A_o \frac{P_u}{\sqrt{RT}} \sqrt{2g \frac{K}{K+1} \left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}}$$

Oxygen Side

The flow of gas to replace 91.6 in.^{3} in 45 seconds assuming a temperature of 68°F and a pressure of 14.5 lb/in.^{2} would be

$$\frac{W}{t} = \frac{PV}{RTt} = \frac{14.5\ \text{lb/in}^2 \times 91.6\ \text{in}^3}{48.3 \times 12\ \frac{\text{in}}{°R} \times 528\ °R \times 45\ \text{sec}} = 96.5 \times 10^{-6}\ \text{lb/sec.}$$

where

$R = 48.3 \times 12$ in/°R for oxygen

$\Delta P = 0.5$ psi is assumed across the Fuel Control Valve.

The flow required to maintain full electrical load will be as follows. Using the Polymer A-Prime data where E = 0.87 volts, the oxygen required is 0.765 lb/KW-hr. For a load of 25 watts this results in a flow of

$$0.765\ \text{lb/KW-hr.} \times \frac{25}{1000}\ \text{KW} \times \frac{1}{3600}\ \frac{\text{hr}}{\text{sec}} = 5.312 \times 10^{-6}\ \text{lb/sec.}$$

In addition, there will be a flow out of the module associated with the decrease in pressure from 15 to 14.5 psia; however, this does not enter into the steady state flow analysis.

The C_dA for the upstream orifice (Fuel Control Valve) is

$$C_dA = \frac{M}{P_u \sqrt{\frac{2g}{RT}\frac{K}{K-1}\left[\left(\frac{P_d}{P_u}\right)^{2/K} - \left(\frac{P_d}{P_u}\right)^{\frac{K+1}{K}}\right]}}$$

where

$M = 101.81 \times 10^{-6}$ lb/sec
$P_u = 15$ lb/in.^{2}
$g = 32.2 \times 12$ in/sec^2
$R = 48.3 \times 12$ in/^oR
$T = 528^oR$
$K = 1.40$
$P_d = 14.5$ lb/in.^{2}

$C_dA = 7.5 \times 10^{-4}$ in.^{2}

The C_dA for the downstream orifice is

$$C_dA = \frac{M}{P_u \sqrt{\frac{2g}{RT}\frac{K}{K+1}\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}}}}$$

where

$M = 96.5 \times 10^{-6}$ lb/sec
$P_u = 14.5$ lb/in.^{2}
$g = 32.2 \times 12$ in/sec^2
$R = 48.3 \times 12$ in/^oR
$T = 528^oR$
$K = 1.40$

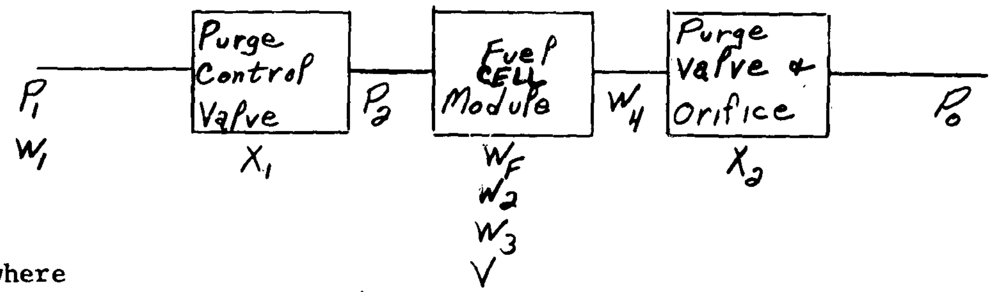
$C_dA = 2.736 \times 10^{-4}$ in.^{2}

Hydrogen Side

The flow required to maintain full electrical load will be as follows. Using the Polymer A-Prime data where E = .87 volts, the hydrogen required is .0955 lb/KW-hr. For a load of 25 watts this results in a flow of

$$0.0955\ \text{lb/KW-hr.} \times \frac{25}{1000}\ \text{KW} \times \frac{1}{3600}\ \frac{\text{hr}}{\text{sec}} = 0.663 \times 10^{-6}\ \text{lb/sec.}$$

The subsystem may be depicted as follows for the purposes of this analysis:

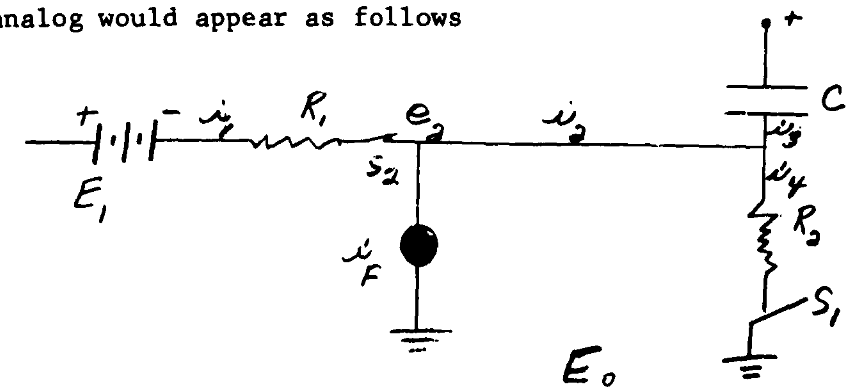


where

- P_1 = regulated inlet pressure.
- W_1 = flow into the Fuel Control Valve and Orifice Assembly. (This will be zero during purging.)
- X_1 = resistance to flow in the Fuel Control and Orifice Assembly.(This will be infinite as the valve will close when the downstream valve opens.
- P_2 = pressure in the module.
- W_F = flow used in the module for conversion to electrical energy.
- W_2 = flow W_1 minus flow W_F.
- W_3 = flow from V module due to decrease in P_2 pressure.
- W_4 = flow into the Purge Valve and Orifice Assembly.
- V = volume of the module and lines from X_1 to X_2.
- X_2 = resistance to flow in the Purge Valve and Orifice Assembly.
- P_o = outlet pressure.

To be better able to analyze the transient of the sub-system to purge valve actuations, an electrical analog will be studied.

The electrical analog would appear as follows



As the desired parameter is the pressure in the module, the analysis will be aimed at obtaining a relation for e_2 as a function of time.

$$-i_3 = i_4 + i_2$$

$$i_4 = \frac{e_2}{R_2}$$

$$i_2 = i_F$$

$$e_2 = \frac{q}{C}$$

$$-i_3 = \frac{\frac{q}{C}}{R_2} + i_F$$

$$-i_3 R_2 = \frac{q}{C} + i_F R_2$$

$$-i_3 R_2 = \frac{\int i_3\,dt}{C} + i_F R_2$$

Differentiating

$$e_2 = (E_1 + i_F R_2)\, e^{-\frac{t}{R_2 C}} - i_F R_2$$

The units for the pneumatic and electrical systems are as follows:

Flow

i = amperes = coulombs/sec.
W = standard cubic feet/sec.

Pressure

E, e = volts.
P = lb/in.^2 abs.

Volume

C = farads
V = cubic feet $\times \dfrac{1}{14.7\,\text{lb/in.}^2} \times \dfrac{528^{\circ}R}{T^{\circ}R} \times \dfrac{14.7\,\text{lb/in.}^2}{P\ \text{lb/in.}^2} = \text{SCF}/\text{lb/in.}^2$

Resistance to flow

$$R = \text{ohms} = \frac{\text{Volts (Voltage Drop)}}{\text{coulomb/sec}}$$

$$X = \frac{\text{lb/in.}^2\ \text{(pressure drop)}}{\text{SCF/sec}}$$

For the purge valve and orifice assembly:

$$W_2 = C_{d_2} A_2 P_2 \sqrt{\frac{2g}{RT_2}} \sqrt{\frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{\frac{2}{K-1}} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]}\ V_S$$

For which

$$X_2 = \frac{P_2}{V_S C_{d_2} A_2 P_2 \sqrt{\frac{2g}{RT_2}} \sqrt{\frac{K}{K-1}\left[\left(\frac{2}{K+1}\right)^{2/K-1} - \left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}\right]}}$$

In pneumatic terms the transient response is:

$$P_2 = (P_1 - X_2 W_F)\, e^{-\frac{t}{X_2 C}} - X_2 W_F$$

$$= \text{lb/in.}^2$$

where

$$X_2 = \frac{\sqrt{R}}{V_S C_{d_2} A_2 \times 2.264 \times .2588}$$

where

$$= \frac{1.706\sqrt{R}}{V_S C_{d_2}' A_2}$$

$$K = 1.40$$

$$\sqrt{\frac{2g}{T}\frac{K}{K-1}} = 2.264$$

$$P_2 = (15 - X_2 W_F) e^{-\frac{t}{X_2 C}} - X_2 W_F$$

For $P_1 = 15 \text{ lb/in}^2$

$$W_F = M_F V_S$$

$$= .0001267 \text{ SCF/sec}$$

$$X_2 = \frac{1.706 \times 95.87}{178 \times \frac{528}{492} C_{d_2} A_2}$$

$$= \frac{.8555}{C_{d_2} A_2}$$

$$V = 25\,in.^3 \times \frac{1}{15 \times 1728}\ SCF/lb/in.^2$$

$$V = 25\,in.^3 \times \frac{1}{15\,lb/in.^2 \times 1728\,\frac{in.^3}{ft.^3}}$$

$$p_2 = \left(15 + \frac{.8555}{C_{d_2} A_2} \times .0001267\right) e^{-\frac{t}{\frac{.8555}{C_{d_2} A_2} \times \frac{25}{14.7 \times 1728}}} - \frac{.8555}{C_{d_2} A_2} \times .0001267$$

For $p_2 = 13\,lb/in.^2$

$$13 C_{d_2} A_2 = 15 C_{d_2} A_2\, e^{-\frac{t C_{d_2} A_2}{.0008422}} + .00010834\, e^{-\frac{t C_{d_2} A_2}{.0008422}} - .00010834$$

$$12 \times 10^4 C_{d_2} A_2 + 1 = (13.85 \times 10^4 C_{d_2} A_2 + 1)\, e^{-\frac{t C_{d_2} A_2}{.0008422}}$$

$$\frac{t C_{d_2} A_2}{.0008422} = \ln \frac{13.85 \times 10^4 C_{d_2} A_2 + 1}{12 \times 10^4 C_{d_2} A_2 + 1}$$

$$t = \frac{.0008422}{C_{d_2} A_2} \ln \frac{13.85 \times 10^4 C_{d_2} A_2 + 1}{12 \times 10^4 C_{d_2} A_2 + 1}$$

$C_{d_2}A_2$	t	d(C_d=0.75)	d(C_d=1)
1×10^{-4}	1.13	.01303	.01129
1.2×10^{-4}	.9475	.01428	.01237
1.4×10^{-4}	.82	.01543	.01336
1.6×10^{-4}	.714	.01648	.01427
1.5×10^{-4}	.762	.01596	.01382

0.75 seconds will be selected which when extrapolated results in a $C_{d_2}A_2$ of 1.525 in.^{2}. This will result in reasonable minimum orifice diameter.

Thus results in orifice sizes as follows for a C_d of 0.75. (0.60 will be used for the Fuel Control Valve.)

Oxygen upstream

$$d = \sqrt{\frac{4}{\pi} \times 7.5 \times 10^{-4} \times \frac{1}{.60}} = \sqrt{15.91 \times 10^{-4}} = .03987 \text{ in.}$$

Oxygen downstream

$$d = \sqrt{\frac{4}{\pi} \times 2.737 \times 10^{-4} \times \frac{1}{.75}} = \sqrt{4.64 \times 10^{-4}} = .02152 \text{ in.}$$

Hydrogen downstream

$$d = \sqrt{\frac{4}{\pi} \times 1.525 \times 10^{-4} \times \frac{1}{.75}} = \sqrt{2.59 \times 10^{-4}} = .01611 \text{ in.}$$

D. Effects of Tolerance in C_dA and Purge Time.

Oxygen Side

The effect of variations in C_dA will result in minor effects on pressure and variations in purge time will have no effect on pressure.

The prime effect will be on the amount of flow flushed through the module. The effect from variations in C_dA of the Fuel Control Valve will be small. The effect from variations in the C_dA of the purge orifice will be significant in that a 10% deviation in C_dA would result in a 10% deviation in flow. The purge time would be equally significant in that a 10% deviation in time would result in a 10% deviation in flow.

As the C_dA and purge time vary independently the root mean square of these deviations may be used as the criterion on which to base the acceptability of reasonable (10%) deviations.

$$\sqrt{\frac{.1^2 + .1^2}{2}} = \sqrt{\frac{.02}{2}} = \sqrt{.01} = .1 \text{ or } 10\%$$

The 10% deviation is considered satisfactory for the system. The maximum deviation would be 20%.

Hydrogen Side

The flow effect is not of concern as the supply flow is shut off.

The pressure effect from deviations in C_dA of the purge orifice and in the purge time will be significant. As these two variables are again independent, the criterion of the root mean square may be used. The effect at the extremes may be determined as follows:

$$P_2 = \left(15 + \frac{.00010834}{C_{d_2} A_2}\right) e^{-\frac{t C_{d_2} A_2}{.0008422}} \qquad \frac{.00010834}{C_{d_2} A_2}$$

C_dA_2		t		P2
% of design	Area	% of design	Time	
100	1.525×10^{-4}	100	.75	13.01
90	1.3725×10^{-4}	90	.675	13.35
110	1.6775×10^{-4}	110	.825	12.62

Thus, with the worst tolerance stackup the pressure is within the required 0.5 psi deviation.

E. Operation At Sea Level Static Conditions.

The mass flows will of course be greater due to the increased density of the gas. The pressures in the module will also be affected and this is the area of prime concern.

Oxygen Side

Since the flow coming in and going out of the fuel module will be almost the same, the flow through the Fuel Control Valve and the downstream orifice will be assumed equal to simplify the solution.

$$M = C_d A_o \frac{P_U}{\sqrt{RT}} \sqrt{2g \frac{K}{K-1} \left[\left(\frac{P_d}{P_U}\right)^{2/K} - \left(\frac{P_d}{P_U}\right)^{\frac{K+1}{K}}\right]}$$

where for the Fuel Control Valve

$$C_d A_o = C_d \frac{\pi}{4} d^2 = .60 \frac{\pi}{4} (.04)^2 = 7.54 \times 10^{-4} \text{ in.}^2$$

$$P_U = 29.7 \text{ psia}$$

$$P_d = P_X$$

where for the orifice

$$C_d A_o = 2.92 \times 10^{-4} \text{ in.}^2$$

$$P_d = 14.7 \text{ psia}$$

Equating the two flows and cancelling common terms results in

$$7.54 \times 10^{-4} \times 29.7 \sqrt{\left(\frac{P_X}{29.7}\right)^{\frac{2}{1.4}} - \left(\frac{P_X}{29.7}\right)^{\frac{2.4}{1.4}}} = 2.92 \times 10^{-4} \times P_X \sqrt{\left(\frac{14.7}{P_X}\right)^{\frac{2}{1.4}} - \left(\frac{14.7}{P_X}\right)^{\frac{2.4}{1.4}}}$$

$$\frac{2.54 \times 29.7}{2.92} = P_x \sqrt{\frac{\left(\frac{14.7}{P_x}\right)^{1.428} - \left(\frac{14.7}{P_x}\right)^{1.714}}{\left(\frac{P_x}{29.7}\right)^{1.428} - \left(\frac{P_x}{29.7}\right)^{1.714}}}$$

This reduces to

$$\frac{P_x^{.286} - 14.7^{.286}}{P_x^{1.142}(29.7^{.286} - P_x^{.286})} = \frac{(7.54 \times 29.7)^2}{(2.92)^2 (29.7 \times 14.7)^{1.428} (29.7)^{.286}}$$

$$\frac{P_x^{.286} - 2.114}{P_x^{1.142}(2.637 - P_x^{.286})} = .438$$

This will be solved by trial and error

P_x	$P_x^{.286}$	$P_x^{.286}-2.114$	$2.637-P_x^{.286}$	$P_x^{1.142}$	$\frac{P_x^{.286}-2.114}{P_x^{1.142}(2.637-P_x^{.286})}$
27	2.568	.454	.069	43.2	.1524
28	2.594	.480	.043	44.9	.2487
29	2.619	.505	.018	46.7	.602
28.5	2.607	.493	.030	45.8	.359

It is thus seen that the pressure will be approximately 28.65 psia resulting in a pressure drop of 1.05 psi as compared to 0.50 psi at orbit conditions.

Hydrogen Side

This will be treated in Section E.

E. Test and Test Analysis

All testing was planned and conducted with nitrogen gas.

Test data was obtained for comparison with the analysis for the hydrogen system using a tank to simulate the hydrogen side of the fuel module (25 in.^{3}) by taking transient recordings of the pressure upstream of the orifice using the oxygen downstream and the hydrogen upstream orifices discussed in Appendix I. Table 3C-1 is a tabulation of the calculated and test data for the pressure decay. These data are shown on Figure 3C-1. Figure 3C-2 shows the test set-up. The orifice is installed in the set-up next to the orifice shown laying on the bench.

TABLE 3C-1.

PRESSURE - PSIA

TIME-SECONDS	Orifice C_dA=.714 in.^{2}			Orifice C_dA=3.566x10^{-4} in.^{2}			
	TEST	THEOR.	TEST	TEST	THEOR.	TIME	TEST
0	15	15	30	15	15	0	30
.3				14.33	14.5	.16	29.3
.5	14.77	14.84	29.46			.36	28.47
.6				13.78	14.02	.56	27.77
.9				13.30	13.53	.76	27.07
1	14.58	14.67	29.0			.96	26.44
1.2				12.865	13.08	1.16	26.1
1.5	14.36	14.51	28.5	12.46	12.65	1.46	25.24
2	14.16	14.34	28.06	11.83	11.95	1.76	25.44
2.5	14.00	14.17	27.62	11.22	11.27	2.06	23.86
3	13.79	14.02	27.16	10.635	10.66	2.46	22.66
3.5	13.53	13.86	26.80	10.12	10.07	2.86	21.67
4	13.44	13.70	26.44	9.6	9.525	3.36	20.67
4.5	13.22	13.54	26.04	9.13	9.01	3.86	19.86
5	13.04	13.38	25.64	8.4		4.36	18.88
5.5	12.86	13.24	25.26	8.23		4.86	18.14
6	12.70	13.09	25.00	7.863		5.36	17.44
6.5	12.55	12.94	24.64	7.463		5.86	16.81
7	12.42	12.80	24.2	7.10		6.36	16.28
8	12.13	12.52	23.66	6.445		6.86	15.82
9	11.80	12.23	23.1	5.80		7.36	15.47
10	11.535	11.95	22.52	5.28		7.86	15.13
						8.36	14.94
						8.86	14.78
						9.36	14.62
						9.86	14.53
						10.36	14.53

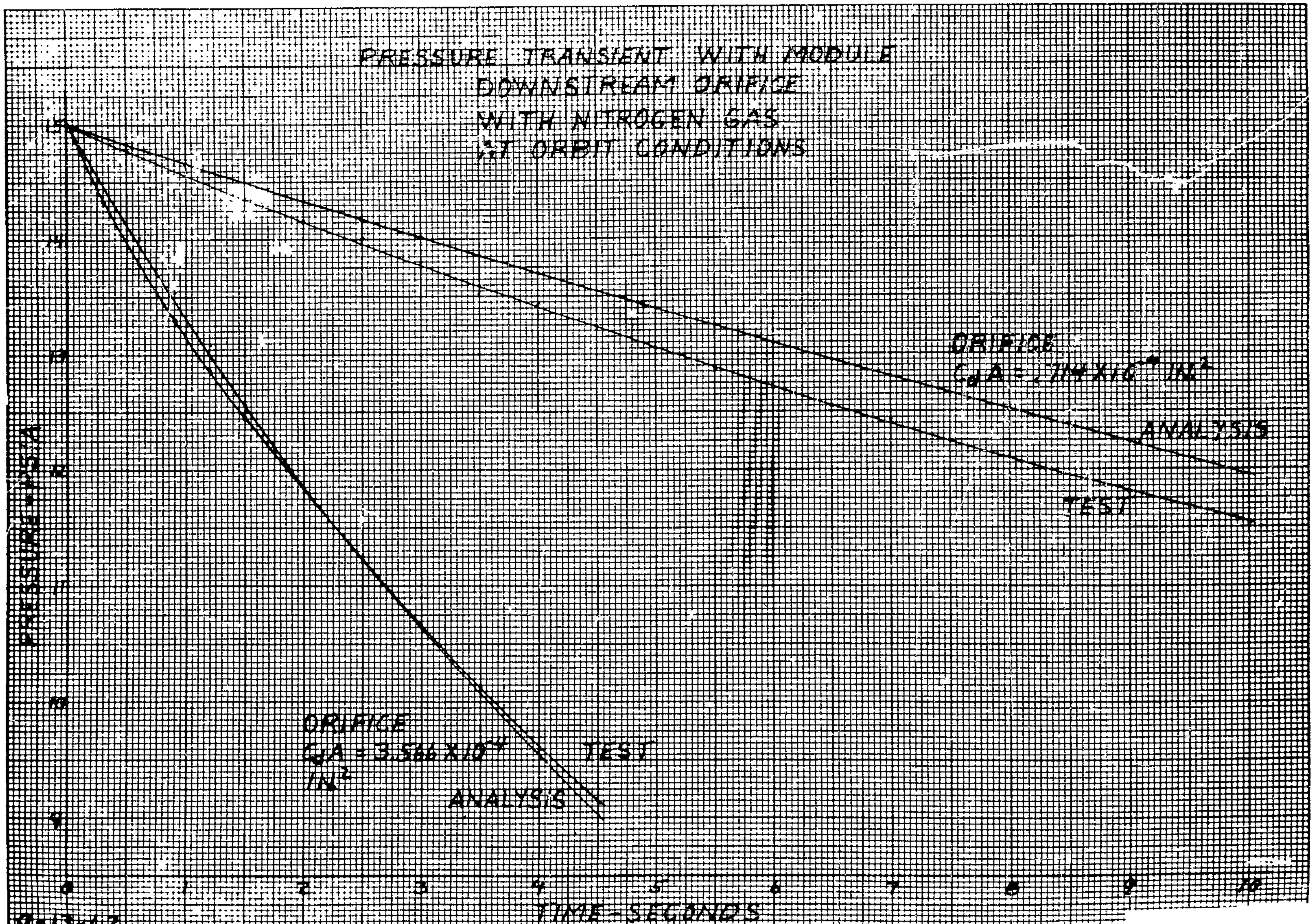

PRESSURE TRANSIENT WITH MODULE
DOWNSTREAM ORIFICE
WITH NITROGEN GAS
AT ORBIT CONDITIONS
ORIFICE
$C_dA = .714 \times 10^{-4}$ IN^2
ANALYSIS
TEST
ORIFICE
$C_dA = 3.566 \times 10^{-4}$
IN^2
TEST
ANALYSIS
PRESSURE - PSIA
TIME - SECONDS
0
1
2
3
4
5
6
7
8
9
10
9-13-62

Figure 3C-1

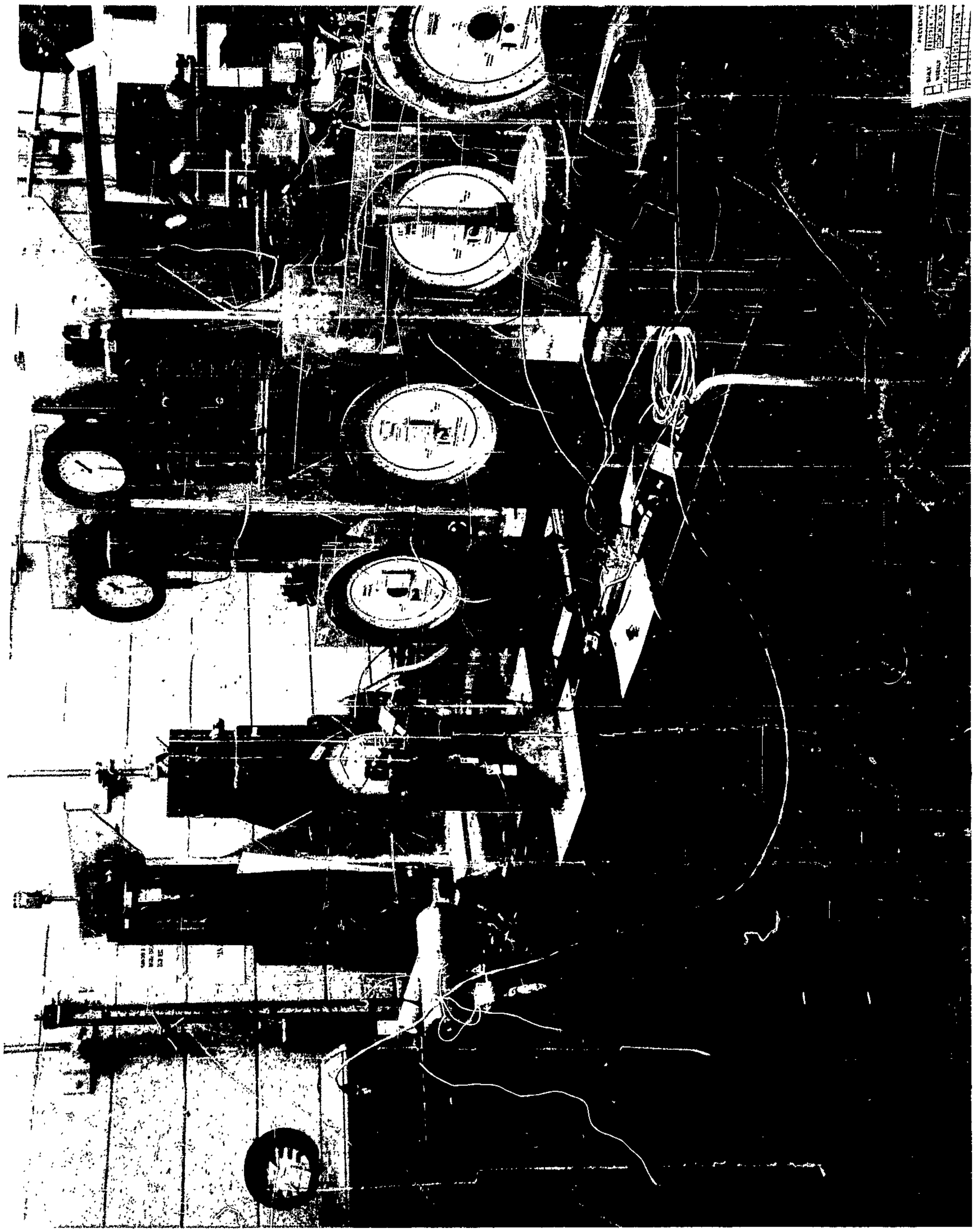


Figure 3C-2

The transient pressure decay for the actual orifices was analytically determined as follows neglecting the $X_2 W_F$ (gas consumed in the module) term.

$$p_2 = P_1 e^{-\frac{t}{X_2 C}}$$

For the hydrogen upstream orifice of Appendix I which has a $C_d A$ of $.714 \times 10^{-4}$ in.^{2} the value of X_2 and p_2 would be

$$X_2 = \frac{1.706 \sqrt{R}}{V_S C_{d_2} A_2}$$

$$= \frac{1.706 \times 25.74}{12.8 \times \frac{528}{492} \times .714 \times 10^{-4}}$$

$$= 44750$$

$$p_2 = 1.5 e^{-\frac{t}{44750 \times \frac{22}{15 \times 1728}}}$$

$$= 15 e^{-\frac{t}{44}}$$

For the oxygen downstream orifice of Appendix I which has a $C_d A$ of 3.566×10^{-4} in.^{2} the value of X_2 and p_2 would be

$$X_2 = 44750 \times \frac{.714}{3.566}$$

$$= 8960$$

$$p_2 = 15 e^{-\frac{t}{8.807}}$$

The result of having neglected the gas consumed in the module may be seen by computing p_2 with and without W_F for the desired orifice having the C_dA of 1.525 in.^{2} for a period of 0.75 seconds where W_F=.0001267 and X_2 is

$$X_2 = \frac{.8555}{C_dA} = \frac{.8555}{1.525 \times 10^{-4}} = 5611$$

$$p_2 = (p_1 - X_2 W_F)\, e^{-\frac{t}{X_2 C}} - X_2 W_F$$

$$p_2 = (15 + 5611 \times .0001267)\, e^{-\frac{0.75}{5611 \times \frac{.25}{15 \times 1728}}} - 5611 \times .001267$$

$$= 13.01 \text{ psia}$$

Neglecting W_F

$$p_2 = 15\, e^{-.1358}$$

$$= 13.08 \text{ psia}$$

To show the difference between the transient pressure decay with nitrogen and hydrogen the following relations are developed with the results tabulated in Table 3C-2 and depicted on Figure 3C-3 for the appropriate C_dA of 1.525x10^{-4} in.^{3}.

For hydrogen

$$p_2 = 15.711\, e^{-\frac{t}{5.516}} - .711$$

For nitrogen

$$W_F = .663 \times 10^{-6} \, lb/sec \sqrt{\frac{767 \times 12}{55.2 \times 12}} \times 12.8 \, ft^3/lb \ @ \ 32°F \times \frac{528}{492}$$

$$= .00003396 \, SCF/sec.$$

$$X_2 = \frac{1.706 \times 25.74}{12.8 \times \frac{528}{492} \times 1.525 \times 10^{-4}}$$

$$= 20930$$

$$p_2 = (15 + 20930 \times .00003396) e^{-\frac{t}{20930 \times \frac{25}{14.7 \times 1728}}} - 20930 \times .00003396$$

$$= (15 + .711) e^{-\frac{t}{20.6}} + .711$$

TABLE 3C-2.

TIME-SECONDS	PRESSURE-PSIA Hydrogen Pressure	Nitrogen Pressure
0	15	15
.1	14.709	
.25	14.317	14.819
.4	13.904	
.5	13.639	14.624
.75	13.009	
1	12.399	14.249
1.5	11.249	13.899
2	10.224	13.539
2.5	9.269	13.209
3		12.759
4		12.222
5		11.609
6		11.029
7		10.459
8		9.944
9		9.439
10		8.959

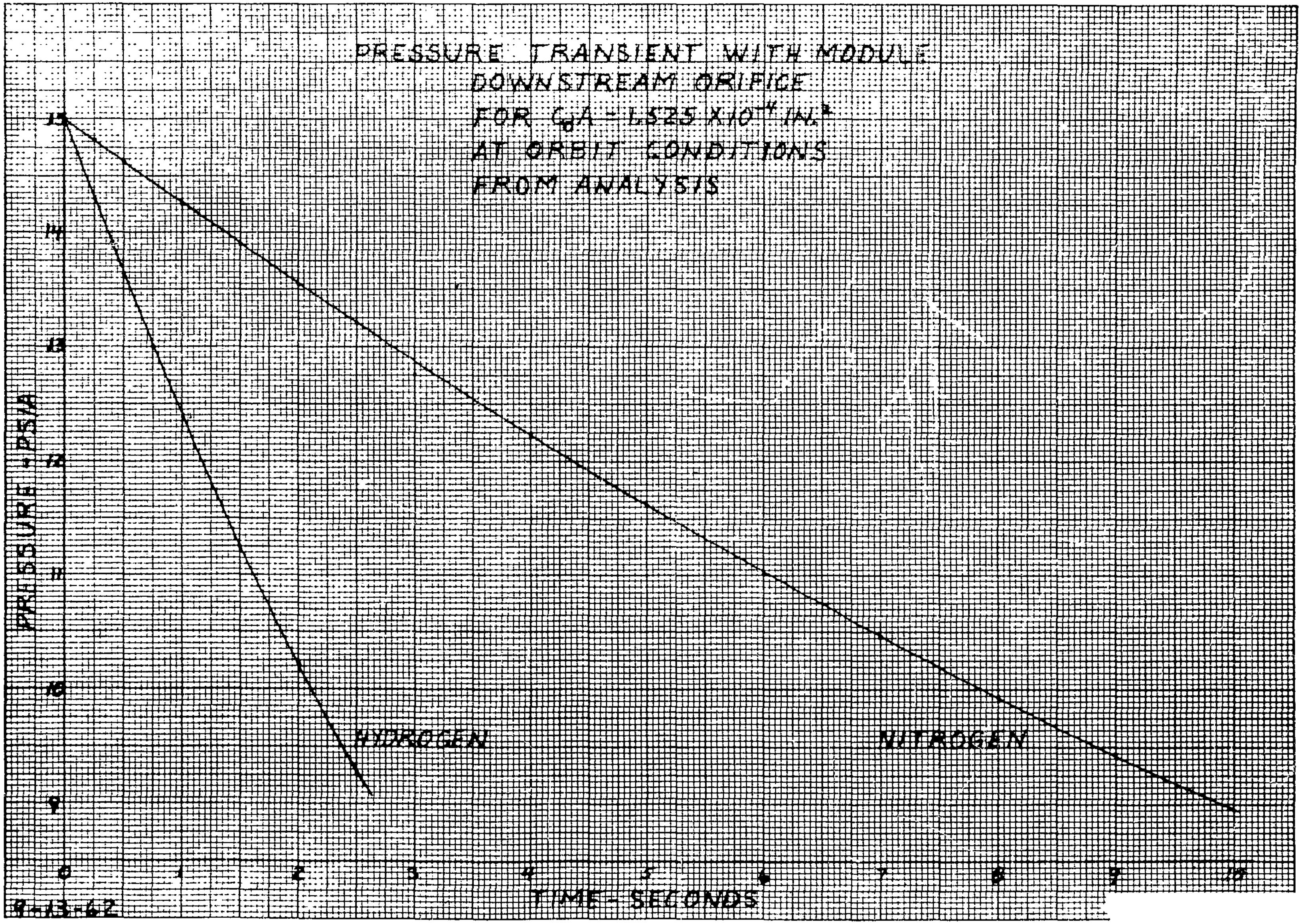

PRESSURE TRANSIENT WITH MODULE
DOWNSTREAM ORIFICE
FOR C_dA = 1.525 X 10^{-4} $IN.^2$
AT ORBIT CONDITIONS
FROM ANALYSIS
PRESSURE - PSIA
15
14
13
12
11
10
9
HYDROGEN
NITROGEN
0
1
2
3
4
5
6
7
8
9
10
TIME - SECONDS
9-13-62

Figure 3C-3

As part of the transient testing recordings were taken for the situation of purging at sea level static conditions, 14.7 psia reference pressure. At this condition the fuel module will be operating at a pressure of 29.7 psia as the pressure regulator regulates at 15 ± 0.5 psig. In addition, the exit pressure will be 14.7 psia rather than 0 psia as in orbit. Comparing these transients as shown on Figure 3C-4 with the transients at orbit conditions, Figure 3C-1, it is seen that pressure decreases very nearly twice as fast from 30 psia as from 15 psia. Thus where the hydrogen pressure decreases from 15 psia to 13 psia in 0.75 seconds at orbit conditions, it will decrease from 29.7 psia to 25.7 psia at sea level conditions giving a 4 psi differential pressure across the membrane. That this should be the case can be deduced by considering that the number of standard cubic feet of gas to be displaced is essentially the same in either case and that with essentially twice the density at the start of the transient the flow would be essentially twice as rapid in the early stages of the transient. A calculation of V in the time constant would also show the effect in that the value for V would be decreased by the ratio of fuel module pressures.

The next phase of the test involved making two of the orifices so as to have a set available for test with a fuel module. As in Appendix I, this requires calculation of the appropriate nitrogen flow.

<u>Oxygen system</u>

$$96.5 \times 10^{-6}\ \text{lb/sec} \sqrt{\frac{18.3 \times 12}{55.2 \times 12}} \times 12.8\ \text{ft}^3/\text{sec} \times \frac{528^\circ R}{492^\circ R} \times 60\ \frac{\text{sec}}{\text{min}} =$$

$$.0746\ \text{SCFM}$$

<u>Hydrogen system</u>

As it would not be practical in test to use transient performance to obtain the proper orifice size, it was sized using the same pressure conditions as for the oxygen system for a C_dA of 1.525×10^{-4}. The C_dA for the oxygen system is 2.737×10^{-4} in.^{2}. Thus the flow required of the hydrogen orifice should be

$$.0746\ \text{SCFM} \times \frac{1.525 \times 10^{-4}}{2.737 \times 10^{-4}} = .04157\ \text{SCFM}$$

After having made the orifices, flow versus pressure drop tests were conducted. The results are plotted on Figure 3C-5 giving a flow of .076 SCFM instead of .0746 SCFM for the oxygen orifice and .0395 SCFM instead of .0416 SCFM for the hydrogen orifice; both of which are within 5% of the desired C_dA. A #79 drill (.0145") was used for the hydrogen orifice and a #76 drill (.0200") was used for the oxygen orifice.

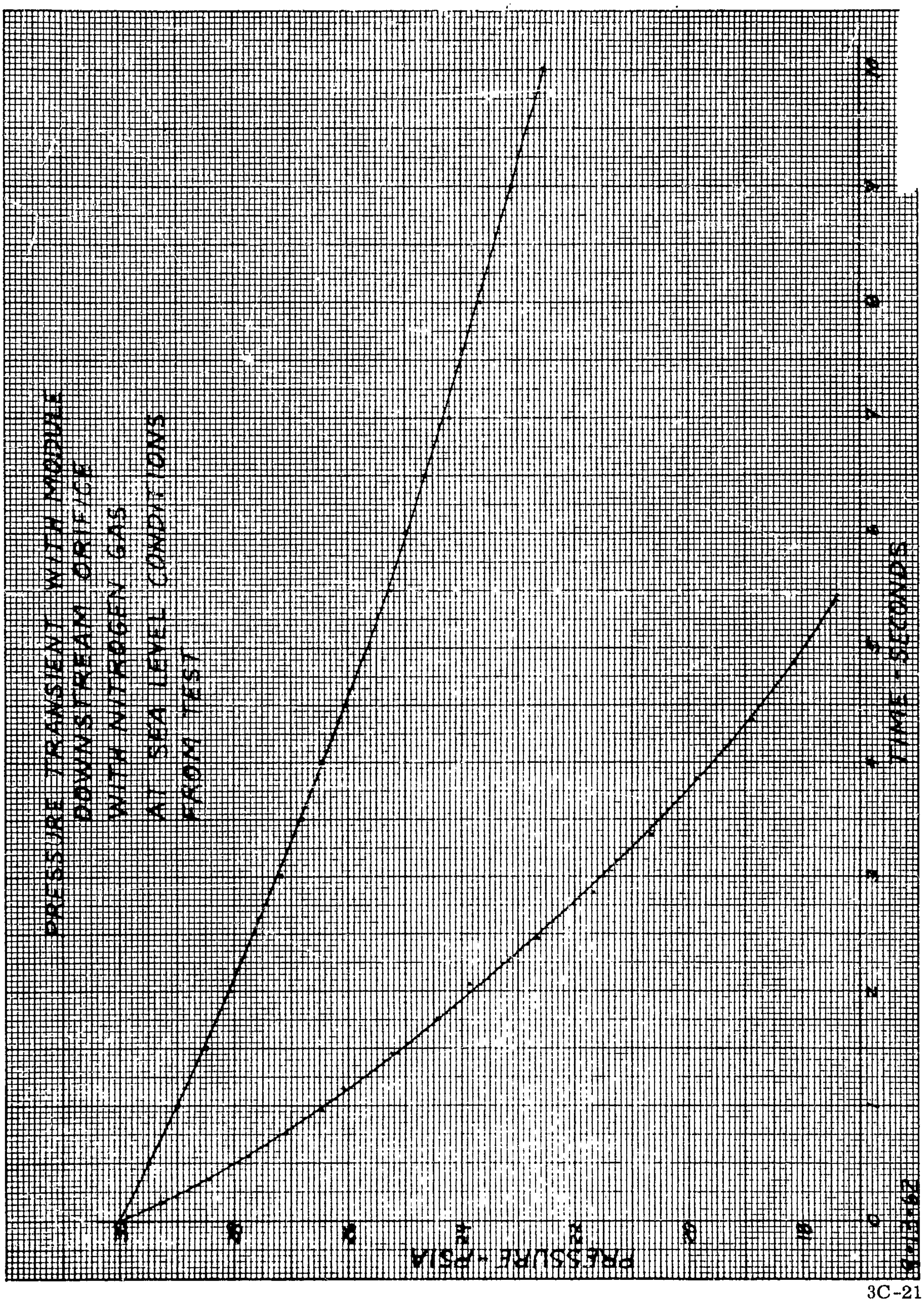
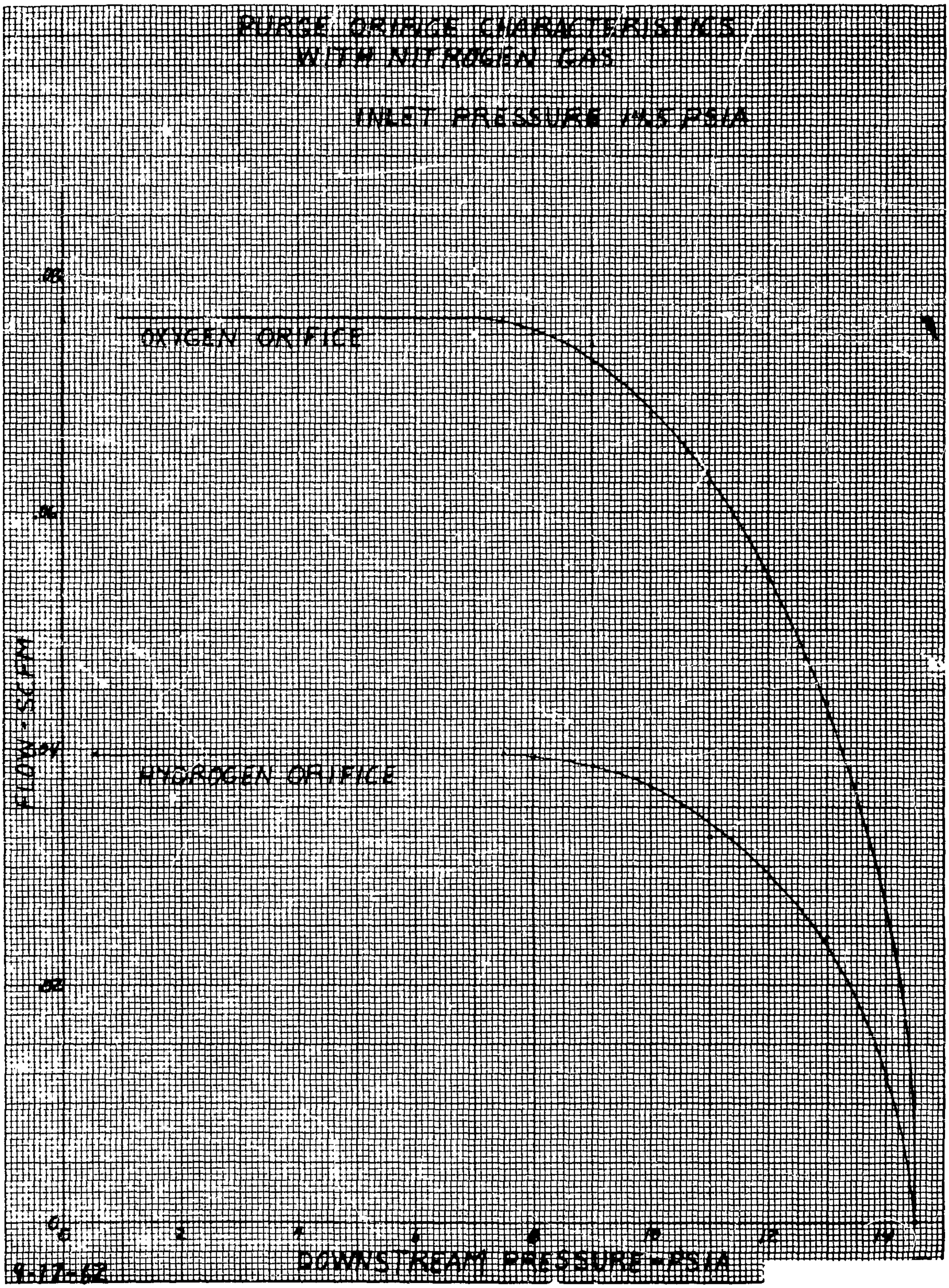

PRESSURE TRANSIENT WITH MODULE
DOWNSTREAM ORIFICE
WITH NITROGEN GAS
AT SEA LEVEL CONDITIONS
FROM TEST
TIME - SECONDS
PRESSURE - PSIA

Figure 3C-4



PURGE ORIFICE CHARACTERISTICS
WITH NITROGEN GAS
INLET PRESSURE 14.5 PSIA
.08
.06
.04
.02
0
FLOW - SCFM
OXYGEN ORIFICE
HYDROGEN ORIFICE
0
2
4
6
8
10
12
14
DOWNSTREAM PRESSURE - PSIA
9-17-62

Figure 3C-5

Aeronautical Systems Division, Flight Accessories Lab., Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-63-181, HYDROGEN-OXYGEN PRIMARY EXTRA-TERRESTRIAL (HOPE) FUEL CELL PROGRAM. Phase Ia Final report, May 63, 621 p. incl. illus., tables, appendices.

The HOPE (Hydrogen-Oxygen Primary Extraterrestrial) Fuel Cell Program is a multi-phase effort to advance the state-of-the-art of fuel cells by obtaining performance data under actual space conditions.

The HOPE program was conceived in early 1960 by the Air Force Aeronautical Systems Division (ASD) as a program to advance the state-of-the-art of primary hydrogen-oxygen fuel cells by obtaining performance data of such energy conversion devices while operating under actual space conditions.

Phase Ia was contracted to provide a Development Test

1. Power System
2. Energy Conversion
3. Electrochemical Devices
4. Fuel Cells; Hydrogen-Oxygen Fuel Cells

I. AFSC Project 8173
Task 817303
II. Contract No.
AF 33(657)-8960
III. General Electric Co.
Philadelphia, Pa.
IV. A. Frank et al.
V. Aval fr OTS
VI. In ASTIA collection

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Vehicle (DTV), Flight Vehicle (FV), and Flight Vehicle Backup (FVB) complete with fuel cells, fuel supply, fuel cell controllers and structural subsystems.

After the Phase Ia program was approximately 50% complete, the program was terminated at the convenience of the government. The prime factors leading to this termination were:

1. The lack of a current operational requirement for fuel cells by USAF.
2. The accelerated development of fuel cells by NASA for the GEMINI and APOLLO programs.

Prior to termination, the fuel cell and pneumatics subsystems had undergone functional testing and a Fuel Cell Controller had been developed. The Development Test Vehicle, complete with all experimental subsystems, was being readied for systems testing.